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RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS (Do-282), Revision A

Meeting #19

Diplexer Transponder Test Results

Presented by: Tom Pagano, FAA TC ACB-410

Summary
This document presents test results from the validation of the performance of ATC transponders when sharing an antenna with a Universal Access Transceiver (UAT) Automatic Dependant Surveillance Broadcast (ADS-B) avionics unit by incorporating an optional passive Diplexer into the installation.

Note: This document was created and posted after Meeting #19, but is associated with Meeting #19 in so much as the requirements that were proposed to modify RTCA DO-282 to specify the requirements for the optional passive Diplexer were proposed in Working Paper UAT-WP-19-10R1, and the data presented in this Working Paper are relevant to the decisions made in that Working Paper.

PERFORMANCE ASSESSMENT OF AIR TRAFFIC CONTROL RADAR BEACON SYSTEM/MODE SELECT (ATCRBS/MODE S) AIRBORNE EQUIPMENT WHEN SHARING AN ANTENNA WITH UNIVERSAL ACCESS TRANSCEIVER (UAT) AUTOMATIC DEPENDANT SURVEILLANCE BROADCAST (ADS-B) AIRBORNE EQUIPMENT USING A PASSIVE DIPLEXER

This document presents test results from the validation of the performance of ATC transponders when sharing an antenna with a Universal Access Transceiver (UAT) Automatic Dependant Surveillance Broadcast (ADS-B) avionics unit by incorporating an optional passive Diplexer into the installation. The purpose of these tests is to insure that the ATC transponders perform according to the applicable standards and that the proposed Diplexer does not introduce any signal distortions on the 1030/1090 MHz frequencies of the transponders. A comprehensive set of tests was performed to measure any potential degradation of equipment performance due to the Diplexer installation.

The Diplexer used for these tests was a prototype unit developed by Lorch Microwave that meets the specifications that are included in Appendix E of the Minimum Operational Performance Standards for UAT ADS-B (RTCA/DO-282A).

Performance Assessment of ATCRBS/Mode S Transponder

The tests were conducted on seven different transponders that included 3 Mode S, and 4 ATCRBS only transponders. The Mode S transponders were made by 3 different manufacturers. Of the four ATCRBS-only transponders, there were two different manufacturers, with two *different* models from each manufacturer.

A comprehensive set of tests was run on each transponder to measure transmitter and receiver characteristics, reply pulse characteristics, side lobe suppression, undesired replies, and pulse decoder characteristics. The Data and Transponder Analysis System (DATAS) was used to perform the tests. DATAS is a system specifically designed to measure performance of ATCRBS/Mode S transponders and provide detailed test results.

Most tests were conducted in two test configurations: (1) with the DATAS connected directly to the transponder, and (2) with the DATAS connected to the antenna port of the Diplexer, which was connected to the transponder under test and the UAT system on the appropriate input channels (see Figure 0). The data from each configuration is compared to determine what effect if any, the Diplexer/UAT installation has on each test parameter.

To minimize the impact of cable losses and connections on test data, short lengths of low-loss cable were used, and the number of cable connections was consistent and kept to a minimum. Because the insertion of a Diplexer into the circuit requires a second cable to connect the Diplexer to the transponder, this cable was also used when a Diplexer was not in the circuit. In this case, the Diplexer was replaced with a short barrel (configuration 1 in Figure 0). During testing it was discovered that some of the parameters were affect by changes in VSWR caused by inserting or removing the Diplexer. For this reason, when appropriate, a slotted line and stub tuner were inserted at the antenna port of the transponder to monitor and control VSWR. A proper installation of an antenna Diplexer will require using appropriate cable lengths between the Diplexer and all attached devices and antennas to control VSWR.

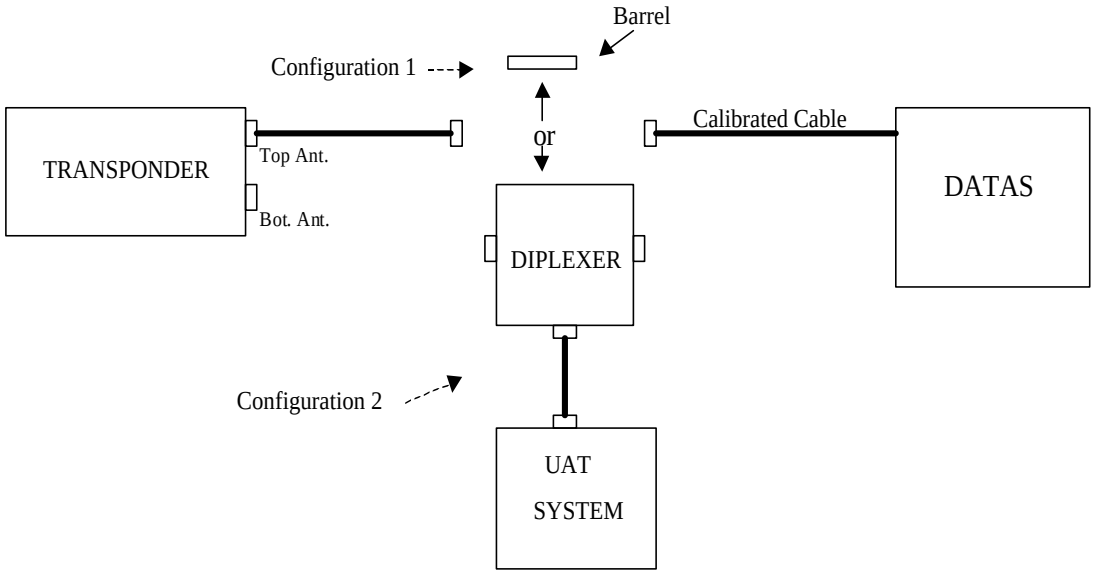

Figure 0 – Diplexer Test Configurations

The UAT was operating in a test mode where it was transmitting at an accelerated rate of 32 PRF. This was done to enhance any potential effect the UAT might have on the transponder performance. In cases where this affected transponder performance, the tests were repeated with the UAT transmitting at the normal 1 PRF and/or not transmitting at all to better ascertain true Diplexer/UAT installation effects.

In the following test data section, the transponders are identified as follows: MS-1, MS-2, and MS-3 are the three Mode S transponders, and A-1, A-2, A-3, and A-4 are the four ATCRBS-only transponders.

SENSITIVITY

The receiver sensitivity of each transponder was measured with and without the Diplexer. The sensitivity measurement procedure determines the minimum signal power required to produce at least a 90% reply probability. To present the effect of the Diplexers on receiver sensitivity, the following graphs show the net change in transponder sensitivity after the addition of the Diplexer/UAT combination.

ATCRBS Sensitivity

Figures 1 and 2 show the average measured change in Mode 3/A and Mode C transponder receiver sensitivity after the installation of the antenna Diplexer. The overall effect is about a 0.26 dB loss of sensitivity with the Lorch WD-00046 Diplexer. The measured sensitivity loss with the Diplexer is consistent with the expected insertion loss (0.5 dB Max.)

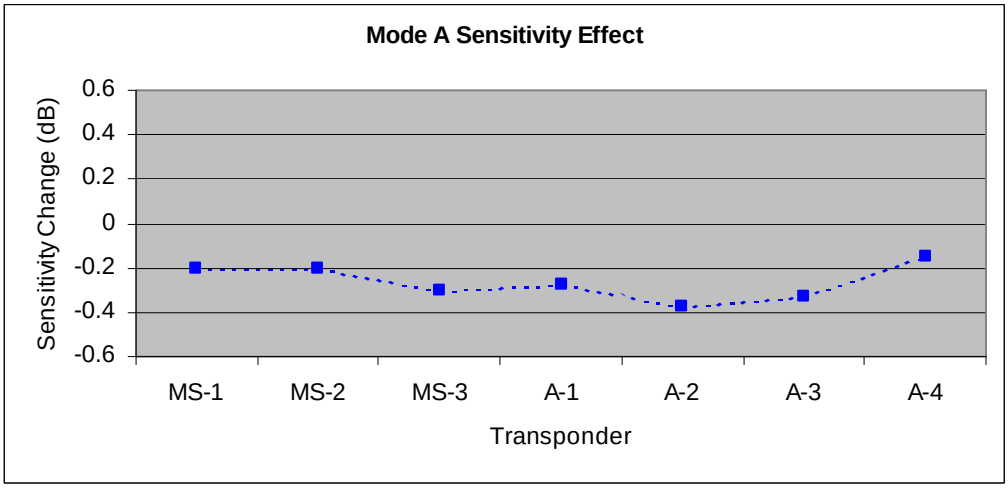

Figure 1 – Mode A Sensitivity

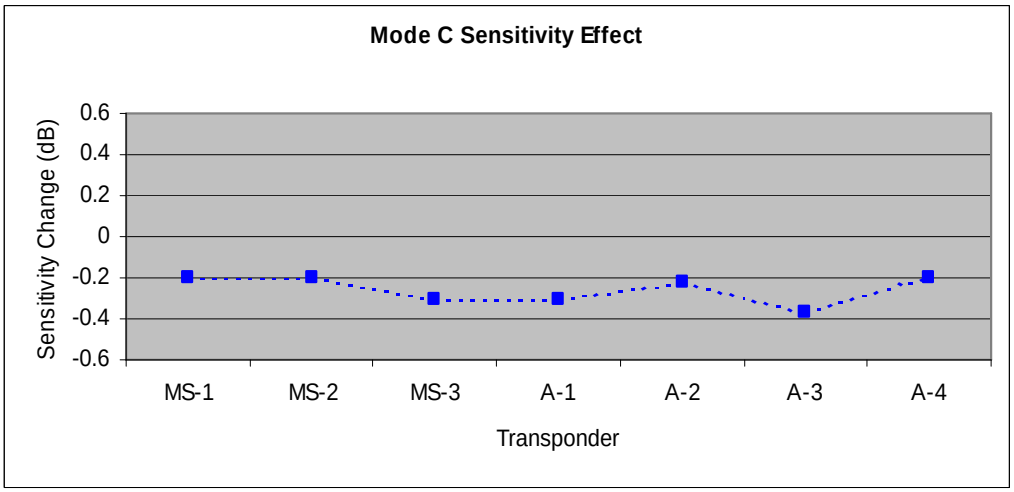

Figure 2 – Mode C Sensitivity

Mode S Sensitivity

The Mode A/Mode S, Mode C/Mode S, and Mode S sensitivities were measured for the Mode S type transponders. The results are presented in Figures 3 through 5. The average overall effect with all three modes is about a 0.24 dB loss with the Lorch WD-00046. Again, this is consistent with the expected values. It is concluded that the effect of an installation of an ATC transponder of either an ATCRBS or Mode S type with a Diplexer will have the expected minimal effect on receiver sensitivity.

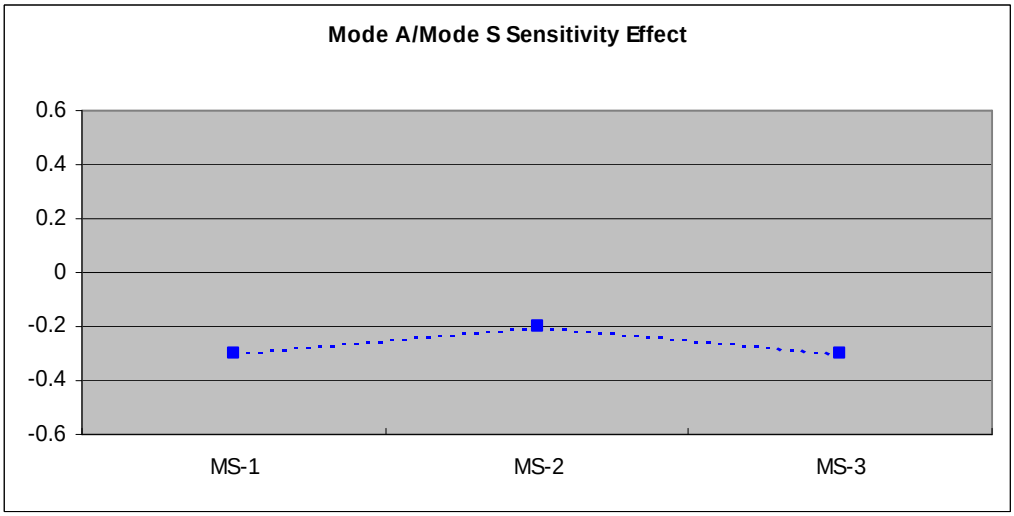

Figure 3 – Mode A/Mode S Sensitivity

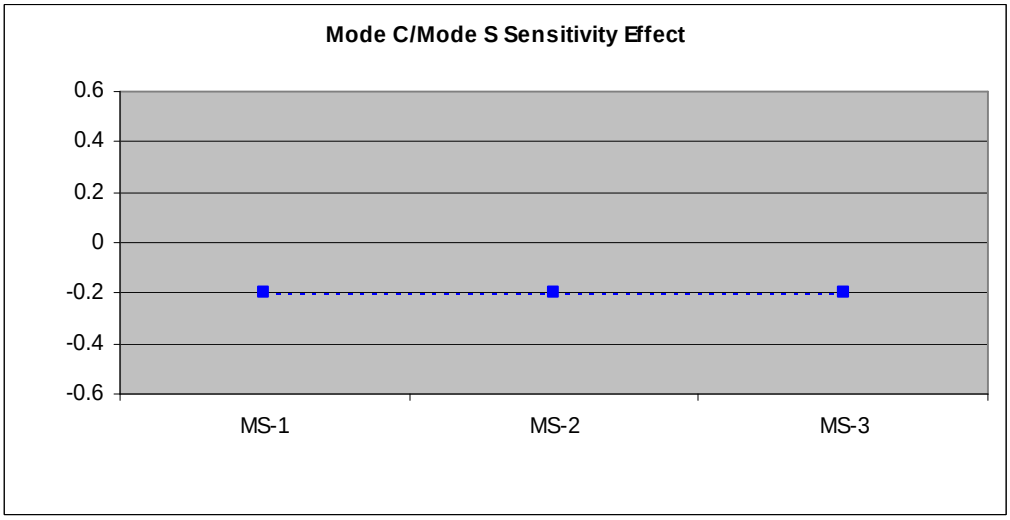

Figure 4 – Mode C/Mode S Sensitivity

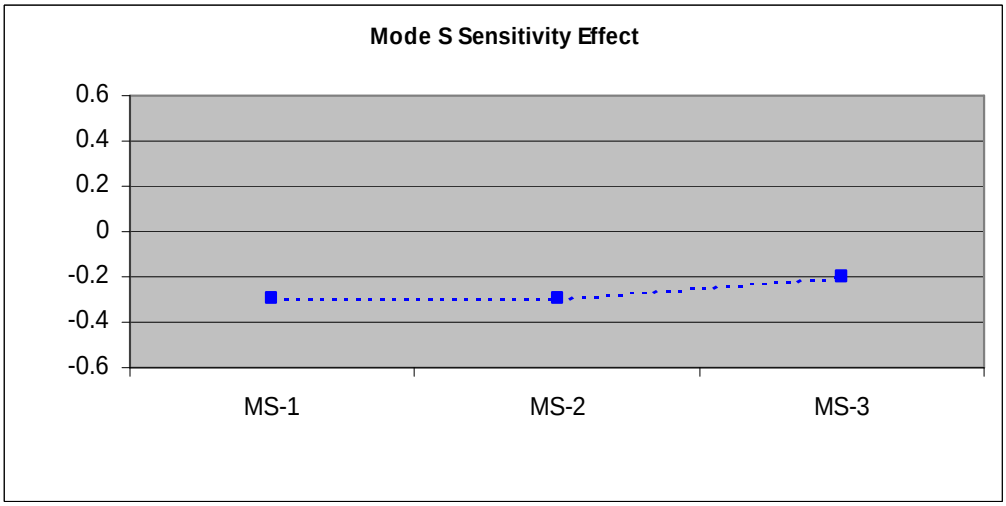

Figure 5 – Mode S Sensitivity

ATCRBS and ATCRBS/MODE S DYNAMIC RANGE

The reply ratio is required to be at least 90 percent for ATCRBS and ATCRBS/Mode S All-Call interrogations between MTL and –21 dBm. The dynamic range tests were performed by varying the interrogation power through the defined range while measuring the average reply rate.

The dynamic range plots show the deviation in cumulative average reply rate at all interrogation amplitudes measured with the Diplexer. The '0' point on the Y axis represents the average reply rate with no Diplexer. The curve shows the relative reply rate measured with the Diplexer. For ATCRBS dynamic range, the interrogation amplitudes used ranged from –20 to –69 dBm in 1 dB steps.

For all dynamic range tests, including Mode S dynamic range, the UAT was configured to transmit at the standard rate (1/Sec.) because the accelerated rate (32/sec.) might have affected the transponder reply rate. The data presented here shows that with an antenna Diplexer installation with a UAT transmitting at the standard once per second rate, there is no measurable effect on the transponder dynamic range.

Figures 6 and 7 show the ATCRBS Mode A and Mode C dynamic range data respectively.

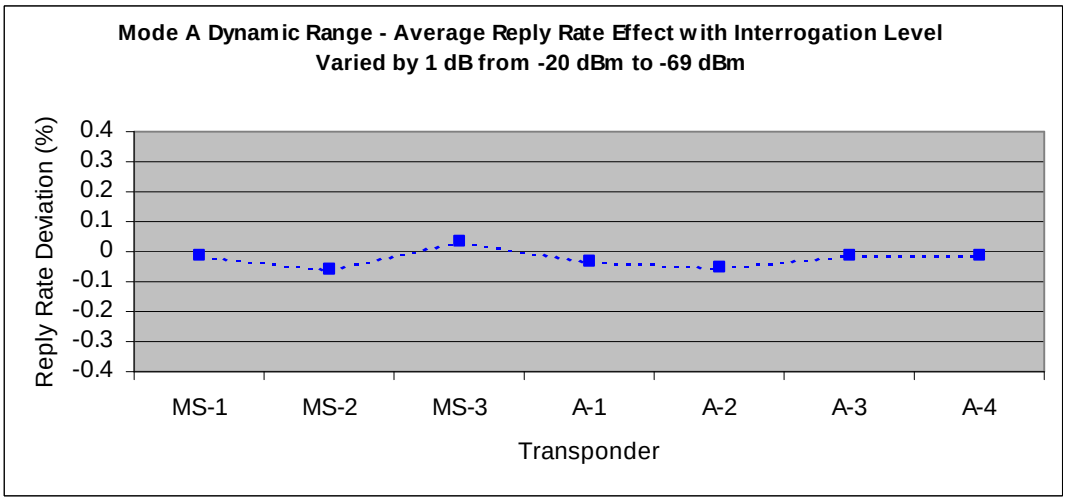

Figure 6 – Mode A Dynamic Range

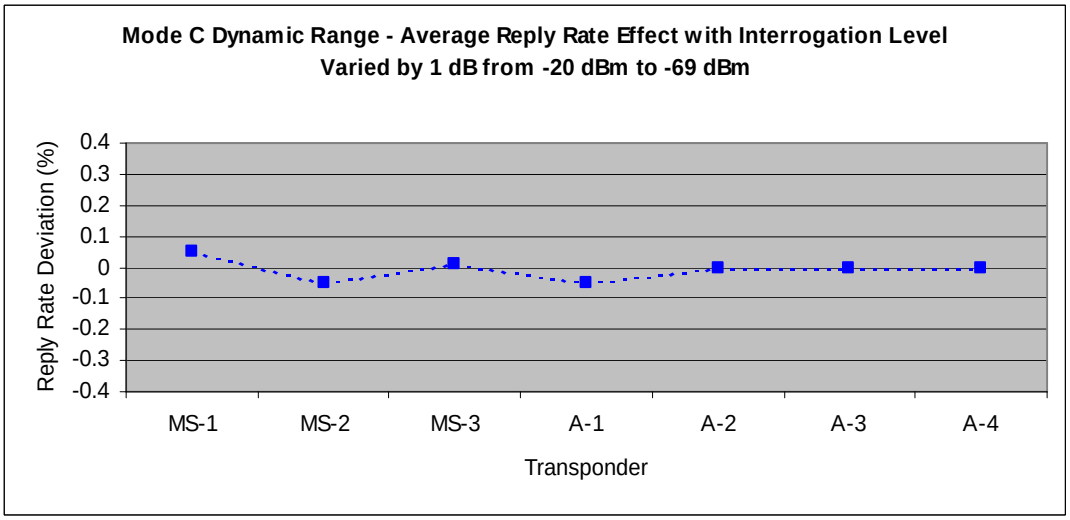

Figure 7 – Mode C Dynamic Range

The ATCRBS/Mode S dynamic range tests were measured in 5 dB steps from –20 to –65 dBm. The 5 dB steps were used to reduce test time because of the lower PRF required for Mode S transmissions yet still provide a sufficient data sample to determine reply rate consistency. The results are presented in Figures 8 and 9 for Mode A/Mode S and Mode C/Mode S dynamic range respectively. The results show no significant effect to reply rate from the Diplexer.

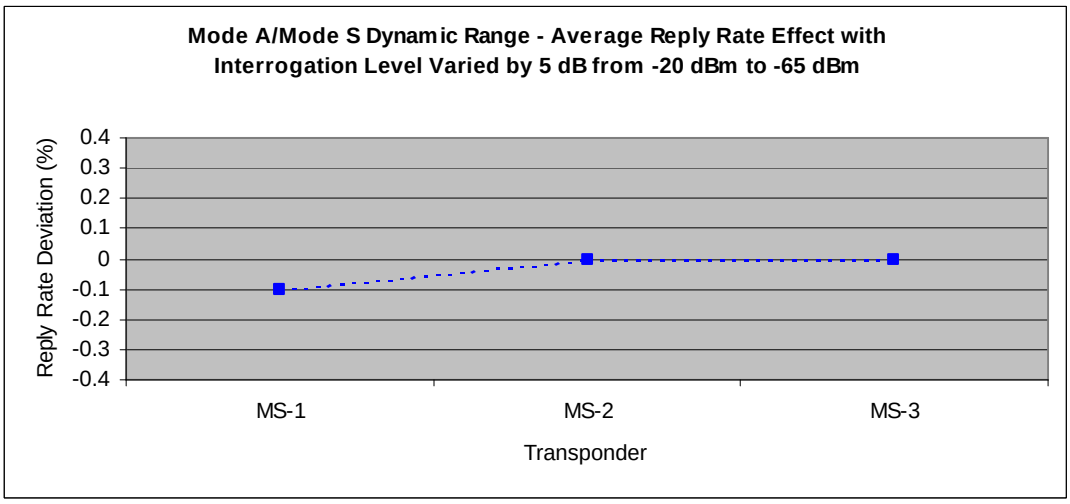

Figure 8 – Mode A/Mode S Dynamic Range

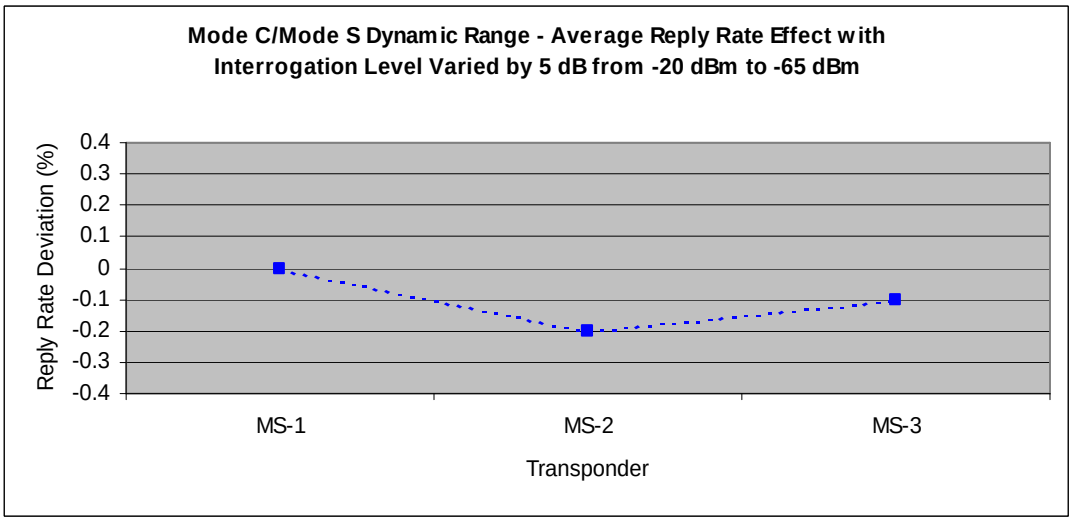

Figure 9 – Mode C/Mode S Dynamic Range

MODE S DYNAMIC RANGE

The reply ratio is required to be at least 99 percent for Mode S interrogations between MTL+3 and –21 dBm. The Mode S dynamic range tests were measured in 5 dB steps from –20 to –65 dBm. The measured reply rates show no significant effect from the Diplexer/UAT installation.

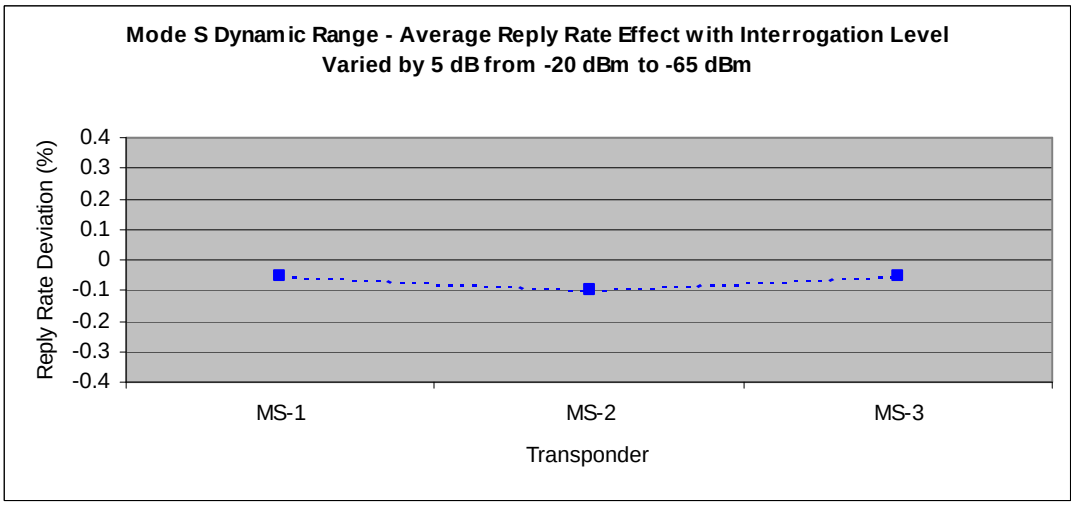

Figure 10 – Mode S Dynamic Range

REPLY DELAY AND JITTER

The ATCRBS reply delay is the time between the arrival of the leading edge of the P3 pulse and the leading edge of the first pulse of the reply. The nominal ATCRBS reply delay is specified to be 3.0 +/- 0.5 microseconds. The DATAS procedure measures the reply delay while varying the signal level between the minimum triggering level and –20 dBm in 5 dB increments and computing the average delay. Figure 11 shows the effect of the Diplexer on reply delay. There is about a 10 nanosecond average increase with the Lorch WD-00046 Diplexer. This is the round trip total delay increase due to the Diplexer. This measurement of delay is only to illustrate the delay of the Diplexer. Reply delay is customarily measured at the transponder port.

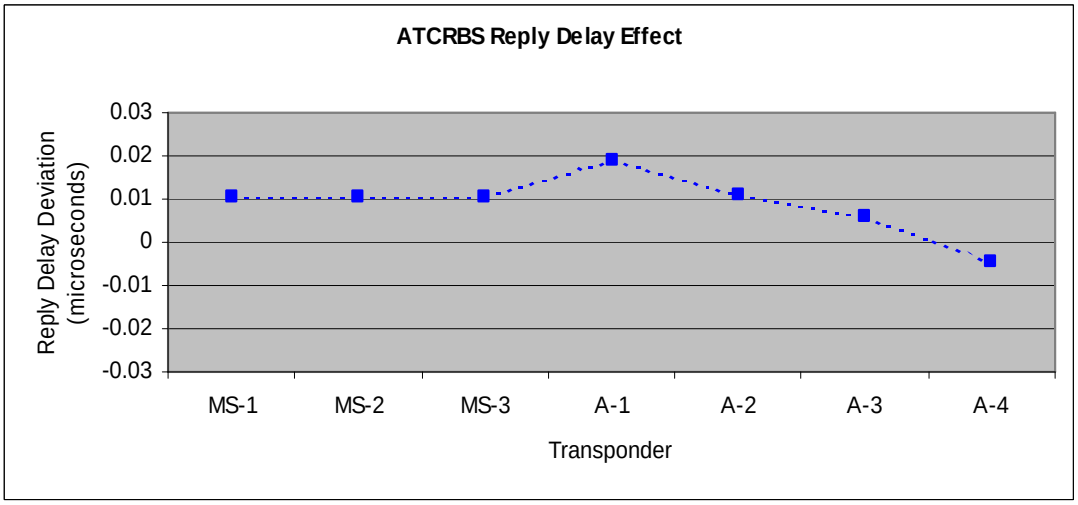

Figure 11 – ATCRBS Reply Delay

ATCRBS reply delay jitter was measured along with the reply delay. Reply delay jitter is the extreme variations in the reply delay through the defined interrogation power range. Figure 12 shows the ATCRBS reply delay jitter deviation with the Diplexer compared to the baseline jitter. There are slight variations in the measured reply jitter both positive and negative that normally occur as the test is repeated. The Diplexer had no measurable effect on ATCRBS reply delay jitter.

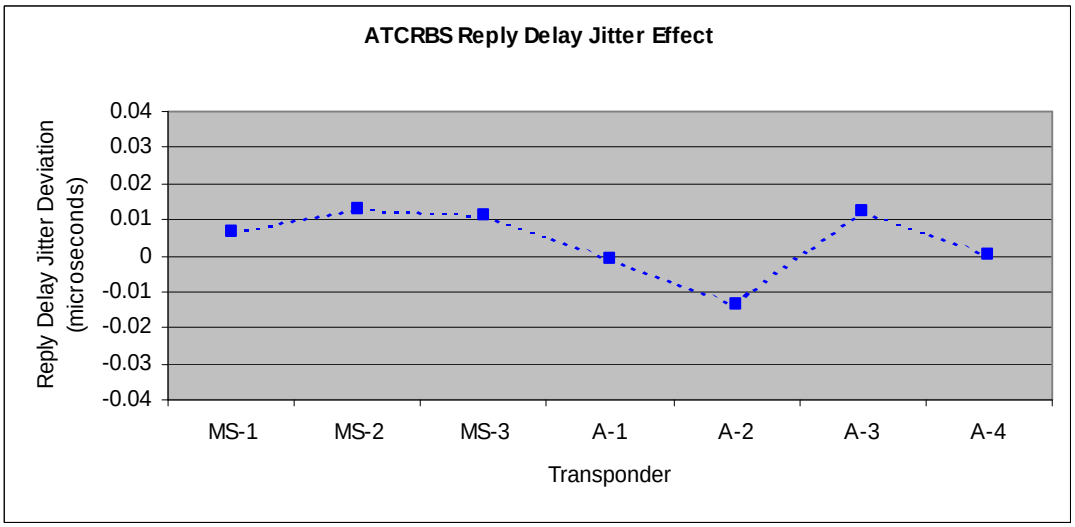

Figure 12 – ATCRBS Reply Delay Jitter

ATCRBS/Mode S reply delay is the time between the leading edge of P4 and the first preamble pulse of the reply. This delay is specified to be 128 +/- 0.5 microseconds at all RF levels from MTL to –21 dBm. The DATAS procedure measures the ATCRBS/Mode S reply delay while varying the signal level between the minimum triggering level and –20 dBm in 5 dB increments and computing the average delay. Figures 14 and 15 show the effect of the Diplexer

on the average reply delay for Mode A/Mode S and Mode C/Mode S interrogations. There is an increase in delay from the Diplexer similar to that measured with the ATCRBS modes of about 12 nanoseconds which includes round trip delay due to the Diplexer.

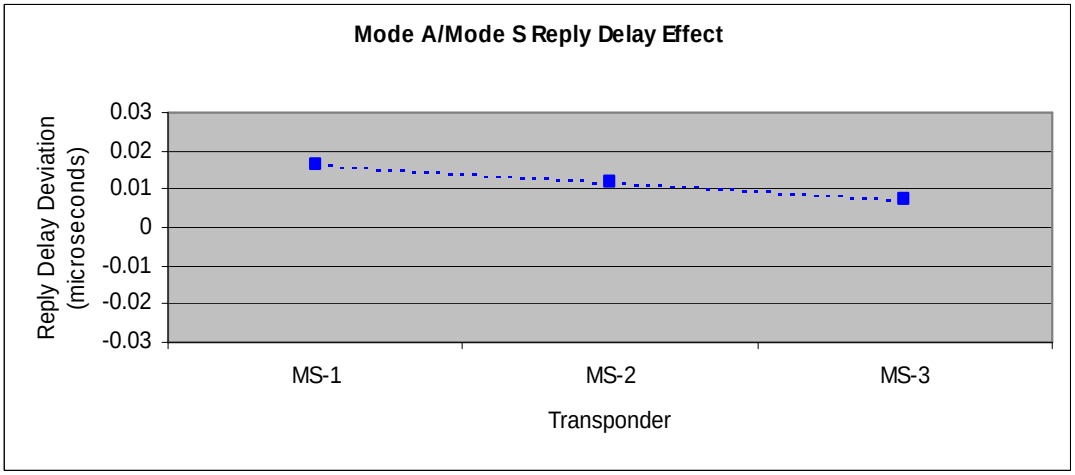

Figure 14 – Mode A/Mode S Reply Delay

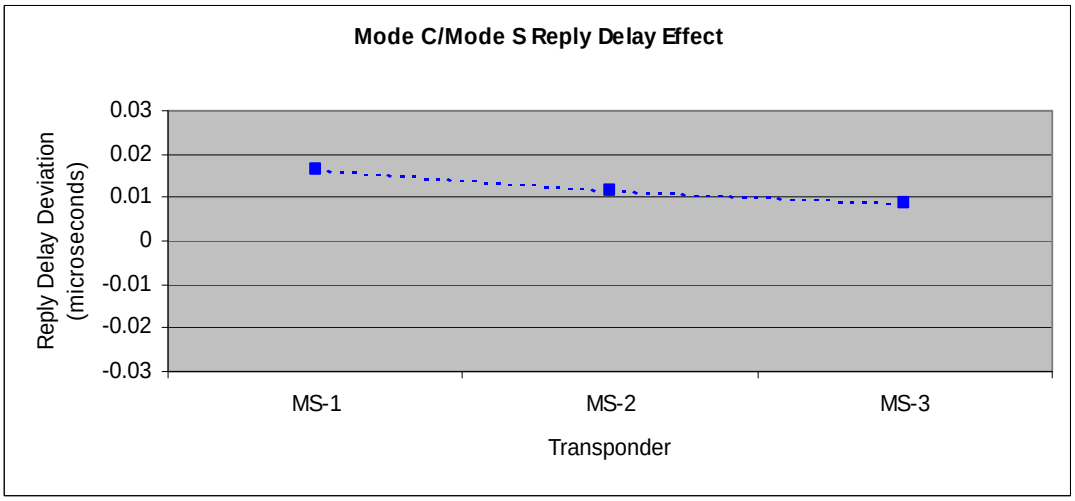

Figure 15 – Mode C/Mode S Reply Delay

ATCRBS/Mode S reply delay jitter was measured along with the reply delay. Reply delay jitter is the extreme variations in the reply delay through the defined interrogation power range. Figures 16 and 17 show the reply delay jitter for Mode A/Mode S and Mode C/Mode S respectively with the Diplexer compared to the baseline jitter. The Data shows no significant effect of the UAT and/or Diplexers on ATCRBS/Mode S reply delay jitter.

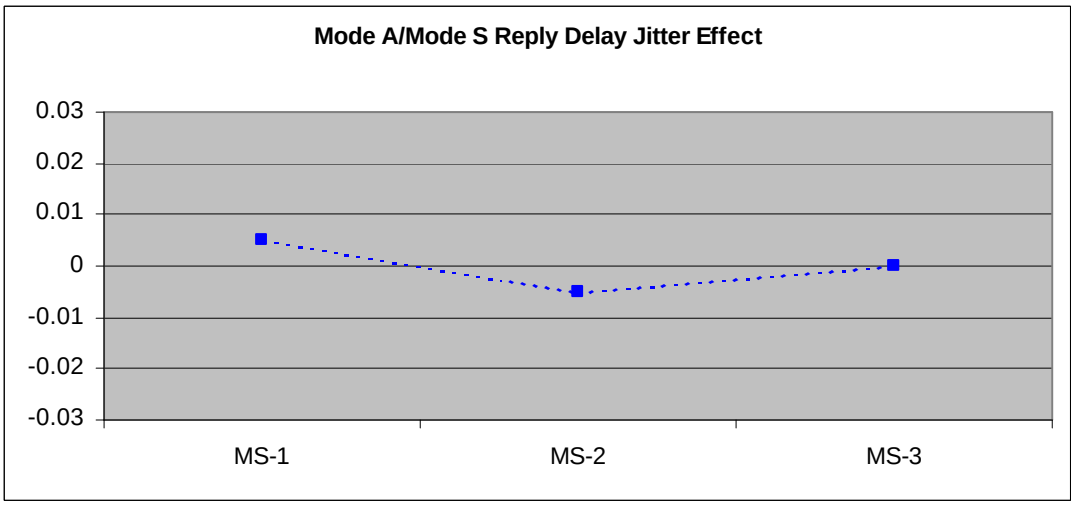

Figure 16 – Mode A/Mode S Reply Delay Jitter

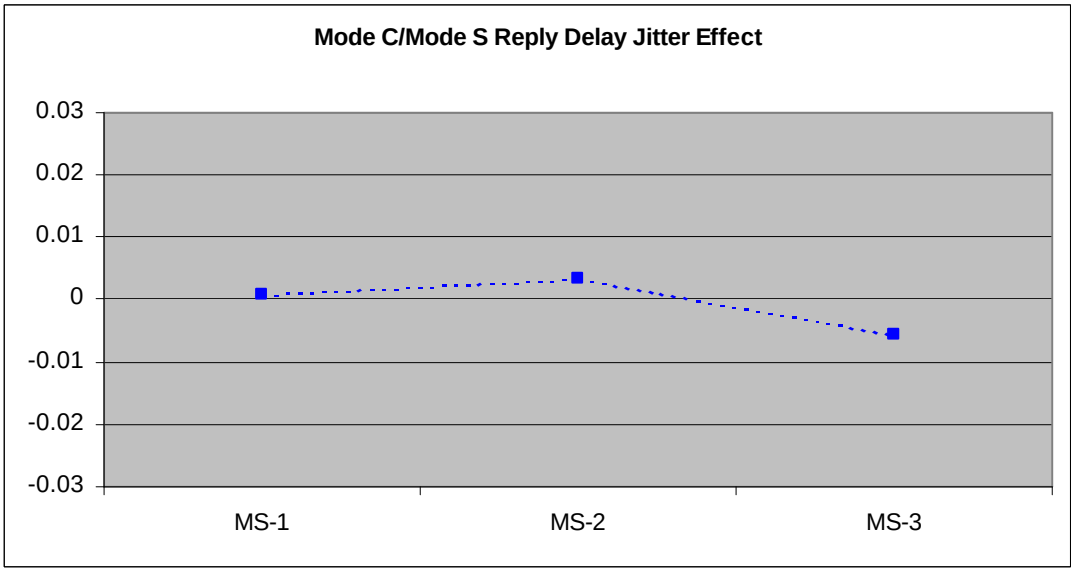

Figure 17 – Mode C/Mode S Reply Delay Jitter

Mode S reply delay is the time between the sync phase reversal of the received P6 and the first preamble pulse of the reply. This delay is specified to be 128 +/- 0.25 microseconds at all RF levels from MTL to –21 dBm. The DATAS procedure measures the ATCRBS/Mode S reply delay while varying the signal level between the minimum triggering level and –20 dBm in 5 dB increments and computing the average delay. Figure 18 shows the effect of the Diplexer on the average Mode S reply delay. There is an increase in round trip delay from the Diplexer similar to that measured with the other modes of about 11 nanoseconds with the Lorch WD-00046 Diplexer.

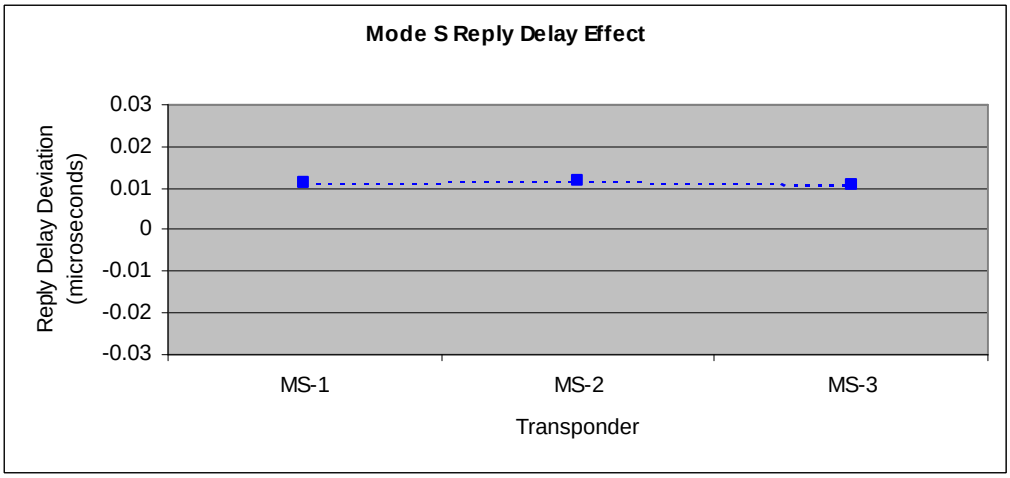

Figure 18 – Mode S Reply Delay

Mode S reply delay jitter was measured along with the reply delay. Reply delay jitter is the extreme variations in the reply delay through the defined interrogation power range. Figure 19 shows the reply delay jitter measured with the Diplexer compared to the baseline jitter. The Data shows no significant effect of the UAT and/or Diplexer on Mode S reply delay jitter.

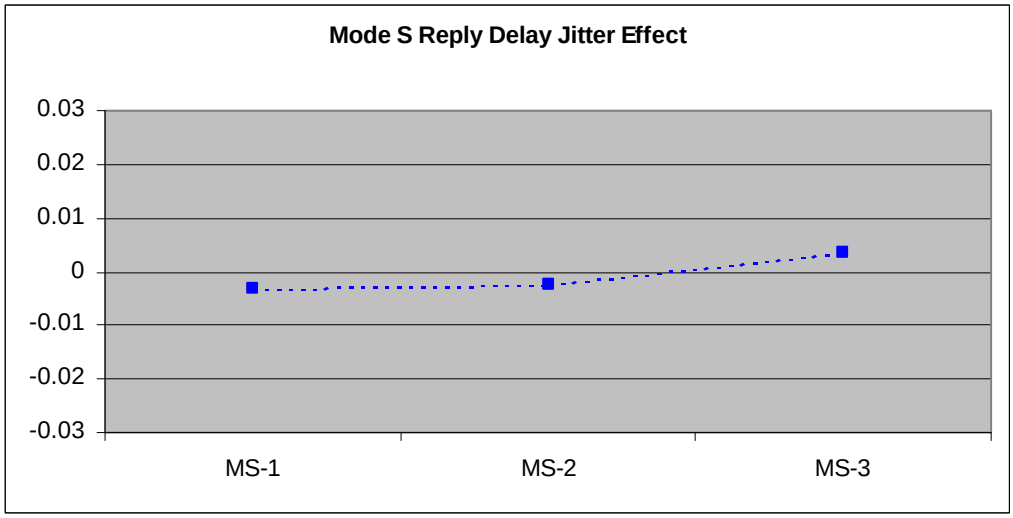

Figure 19 – Mode S Reply Delay Jitter

REPLY TRANSMISSION FREQUENCY

Tests were performed to measure the reply transmission frequency of the transponders. The DATAS test procedure automatically samples the frequency of each reply pulse and a minimum of 100 reply pulse groups were used to measure the average reply transmission frequency of each transponder. Figure 20 shows the average deviation in reply frequency measured with each transponder after installing the Diplexer. There were no significant variations in reply frequency with the Mode S transponders. The ATCRBS transponders showed a frequency variation of up to about 1.5 MHz. Further testing determined that this variation is not directly due to the Diplexer, but due to the Diplexer installation changing the VSWR. Similar results were obtained just by installing various cable lengths with no Diplexer. A slotted line was installed to measure VSWR and it was verified that there is a change in VSWR when the Diplexer is installed. Frequency shift can be abated when installing a Diplexer by properly adjusted cable lengths to minimize VSWR and adjusting the transmitter frequency of the transponder if necessary.

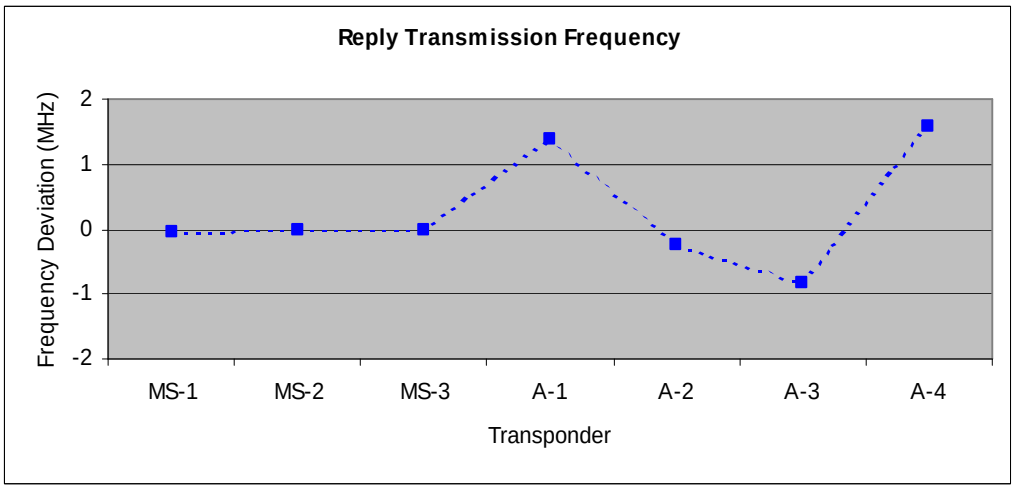

Figure 20 – Reply Transmission Frequency with Uncontrolled VSWR

REPLY POWER

The ATCRBS and Mode S RF power output of each transponder was measured with and without the Diplexer. The measurement procedure determines the reply power by computing the cumulative reply power of all pulses from a sample of 100 replies. To compare the effect of the Diplexer installation, Figures 21 and 22 show the change in reply power of the transponder after the addition of the Diplexer/UAT combination for ATCRBS and Mode S replies respectively.

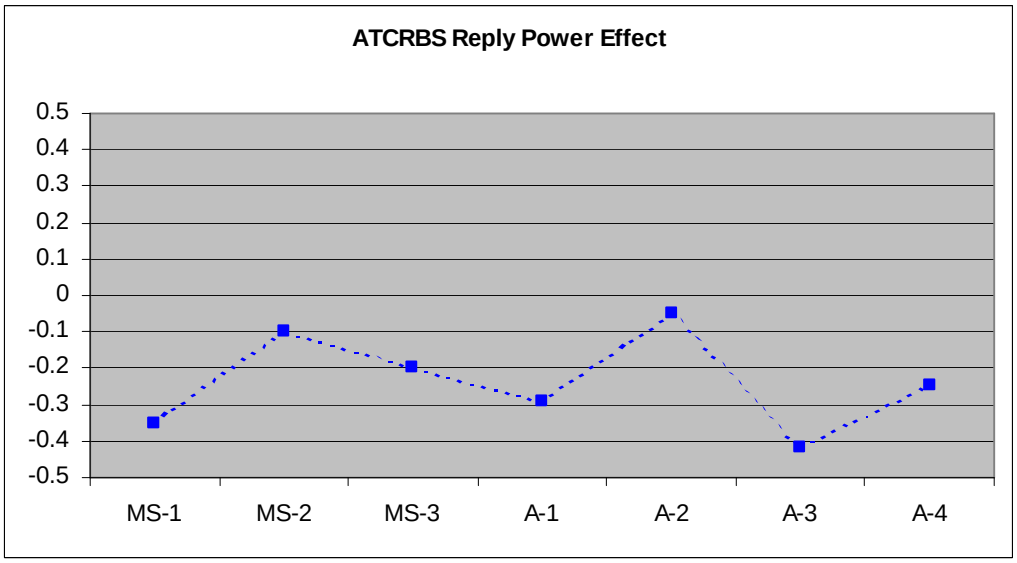

Figure 21 – ATCRBS Reply Power

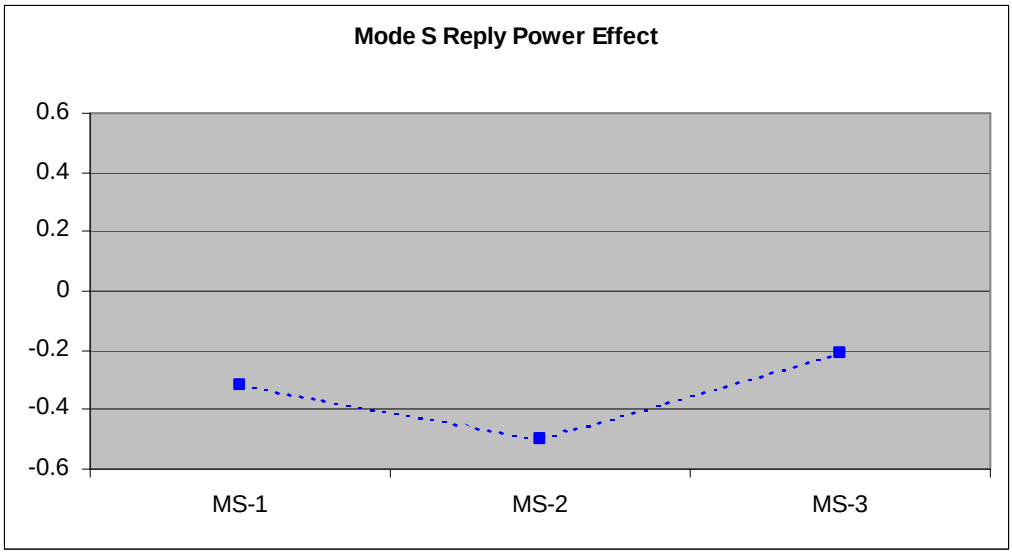

Figure 22 – Mode S Reply Power

The data shows that the Lorch WD-00046 Diplexer reduced the ATCRBS power output an average of about 0.24 dB. This average includes both ATCRBS and Mode S type

transponders. The Diplexer reduced the Mode S reply power an average of about 0.34 dB. The reduction in reply power is within the expected range.

REPLY PULSE SPACING

The ATCRBS reply pulse spacing for all reply pulses is required to be within +/- 0.10 microsecond with respect to the first framing pulse. With each run of the DATAS test procedure, 100 replies are acquired and the average position error of each reply pulse is recorded. To measure the Diplexers' effect, if any, the cumulative average reply pulse position error of all reply pulses is compared with and without the Diplexer. The results are shown in Figure 23.

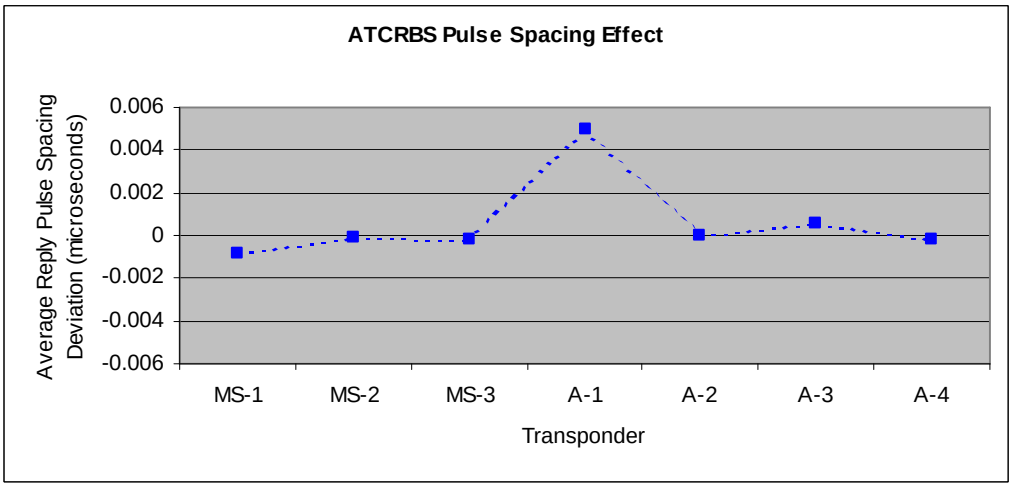

Figure 23 – ATCRBS Reply Pulse Spacing

There is no significant effect on pulse spacing from the Diplexers. The maximum effect measured was only about 5 nanoseconds (transponder A-1) and that may be attributed to the margin of measurement error for this transponder. Subsequent measurement samples with transponder A-1 showed variations in pulse spacing from as high as 9 nanoseconds and as little as 1 nanosecond. The data in Figure 23 is the average of all samples. Also, the reply pulse spacing deviation measured with the Lorch Diplexer was much less with all other transponders.

The Mode S reply pulse spacing tolerance is 50 nanoseconds of the nominal position. The DATAS test procedure acquires 100 replies and measures the average position error of each reply pulse. The maximum pulse position error of all pulse samples is compared with and without the Diplexer in Figure 24.

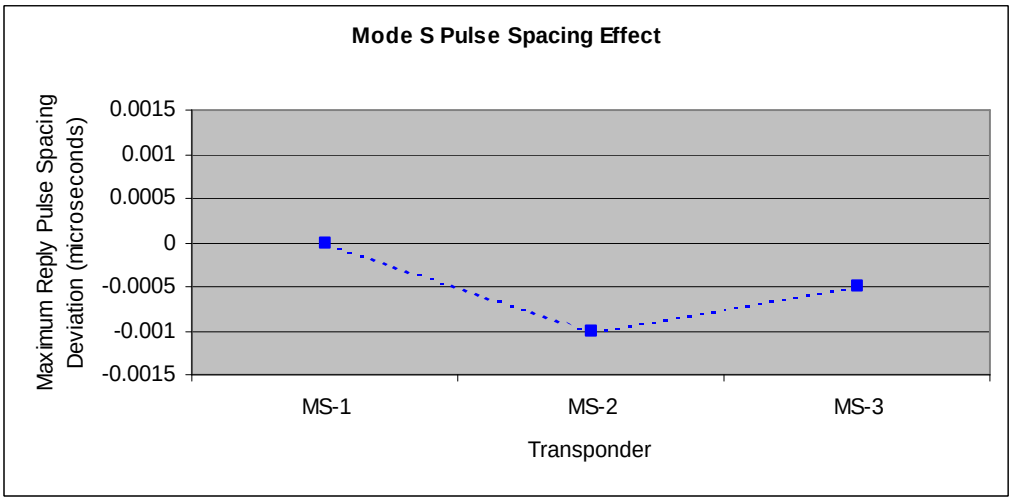

Figure 24 – Mode S Reply Pulse Spacing Error

REPLY PULSE WIDTH

ATCRBS reply pulse width is required to be within 100 nanoseconds of nominal. The DATAS test procedure acquires a sample of 100 replies and determines the average width of each reply pulse. The pulse width measurements were compared with and without the Diplexer. The results are presented in Figure 25. The pulse width variation is minimal and is both plus and minus. The data indicates no significant effect on reply pulse width.

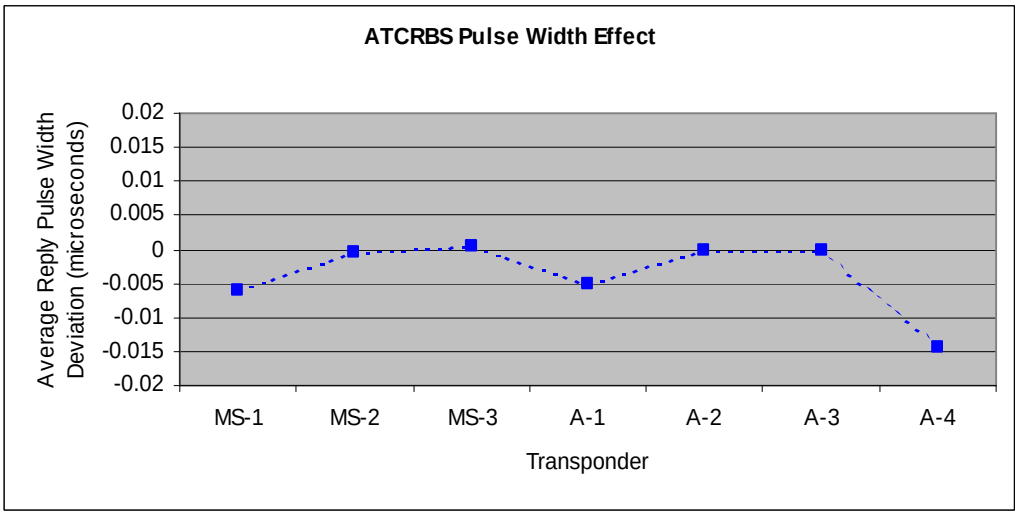

Figure 25 – ATCRBS Pulse Width

Mode S reply pulse width is required to be within 50 nanoseconds of nominal. The DATAS test procedure acquires a sample of 100 replies and determines the average pulse width. The pulse width measurements were compared with and without the Diplexer. The results are presented in Figure 26. The data shows no significant effect with any of the transponders from the Diplexer.

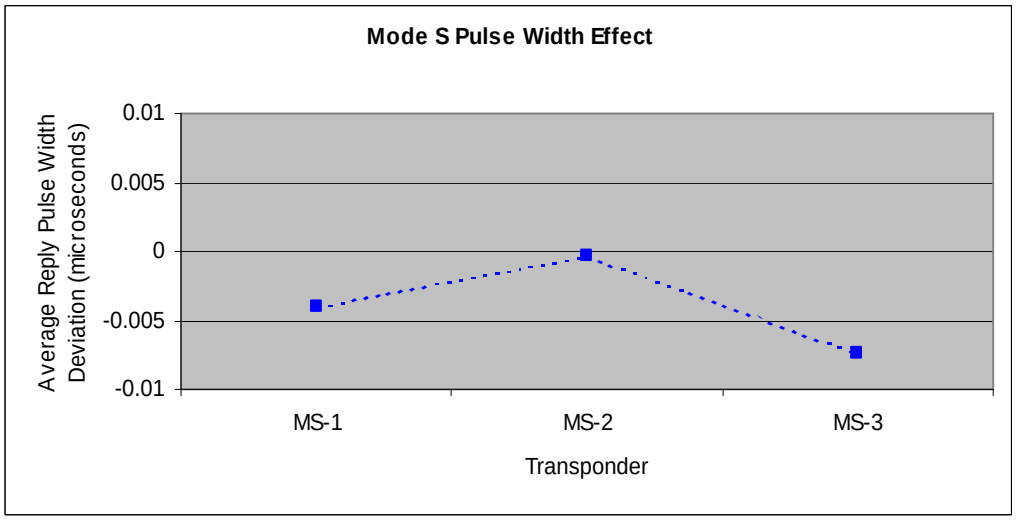

Figure 26 – Mode S Pulse Width

UNDESIRED REPLIES

The Undesired reply rate was measured by monitoring ATCRBS and Mode S reply transmissions without interrogating the transponder. The undesired reply rate for ATCRBS modes is required to be 5 replies per second or less averaged over a 30 second interval. (This is the requirement for Mode S transponders – RTCA/DO-181C) The required undesired reply rate for Mode S replies is no more than once per 10 seconds. The transponders were monitored for undesired replies for at least five 60-second intervals to obtain an average reply rate. Some transponders that exhibited undesired replies were tested up to ten 60-second intervals to get a better average rate. Table 1 shows the measured results.

TRANSPONDER	NO DIPLEXER	LORCH WD-00046
MS-1	0	0
MS-2	0	0
MS-3	0	0
A-1	0	0
A-2	0.2	8.67
A-3	0	0
A-4	0	0

Table 1 – Average Undesired ATCRBS Replies in 60 Seconds (UAT @ 32 PRF Test Rate)

The data in Table 1 shows the average number of undesired ATCRBS replies in a 60-second interval for each transponder and Diplexer combination. One of the ATCRBS

transponders showed a slight increase in the undesired reply rate when configured with the Diplexer. None of the transponders transmitted any undesired Mode S replies in any configuration. According to RTCA/DO-181C, the transponders are allowed up to 300 unsolicited replies in 60 seconds (5 per second). As with the other tests, the UAT was transmitting at an increased rate of 32 signals per second in order to amplify any potential effects therefore the undesired reply rates shown in Table 1 are much greater than would normally occur. In order to assess the undesired reply rate with normal UAT installation conditions the tests were repeated with the same configurations but with the UAT transmitting at the standard 1 per second rate. These measurements are presented in Table 2.

TRANSPONDER	NO DIPLEXER	LORCH WD-00046
MS-1	0	0
MS-2	0	0
MS-3	0	0
A-1	0	0
A-2	0.2	3.4
A-3	0	0
A-4	0	0

Table 2 – Average Undesired ATCRBS Replies in 60 Seconds (UAT @ 1 PRF Test Rate)

Table 3 shows the probability of an undesired reply being triggered by a single UAT transmission for each Diplexer/transponder combination. These numbers were derived by dividing the number of replies in 60-seconds by the number of UAT transmissions in 60-seconds for the two UAT transmission rates tested. There is some variation in the undesired reply rate but the per transmission rate is fairly consistent for the two UAT transmission rates. These numbers effectively show the number of undesired replies per second since there is normally 1 UAT transmission per second. Although the undesired reply rates are quite low, any increase in the undesired reply rate is not desirable and the suppression bus is a requirement when installing UAT equipment with on-board SSR transponders to prevent such transmissions. UAT will only drive the suppression bus to suppress other on-board L-Band systems but will not receive suppression signals since UAT transmissions rely on exact timing for transmissions.

TRANSPONDER	LORCH WD-00046	
	UAT @ 1/sec	UAT @ 32/sec
MS-1	0	0
MS-2	0	0
MS-3	0	0
A-1	0	0
A-2	.0567	.004
A-3	0	0
A-4	0	0

Table 3 – Number of Undesired ATCRBS Replies per UAT Transmission

SENSITIVITY VARIATION WITH FREQUENCY

While varying the RF signal frequency over the range 1029.8 to 1030.2 MHz, the variation in RF signal level required to produce a 90 percent reply rate must not exceed 1 dB. An assessment of Mode S sensitivity variation with frequency was performed. Mode S interrogation formats were used in this case since the Digital Phase Shift Keying (DPSK) modulation requires a wider bandwidth than that of simple pulse leading edge detection. Of interest is whether the Diplexer will accommodate the wider bandwidth required by Mode S DPSK interrogation types, and whether the pass-band of the Diplexer has any limiting effects as the frequency is varied.

Figure 27A shows a plot of the Sensitivity Variation with Frequency measurements for transponder MS-1. The interrogation used consisted of a UF code of '4' and all other data bits equal to binary '1' except the Address Parity (AP) field which was properly coded to elicit a response from the transponder. The all binary 1's format was used to maximize the number of phase shifts in the uplink interrogation. This was the primary interrogation format used to test all three transponders. It was intended to use a long format interrogation. However, since there was no adequate means of connecting the ARINC 429 interface of the three transponders, the transponders would not reply to long interrogation formats. The data shows a consistent average reduction in sensitivity of about 0.2 dBm that does not vary significantly with frequency.

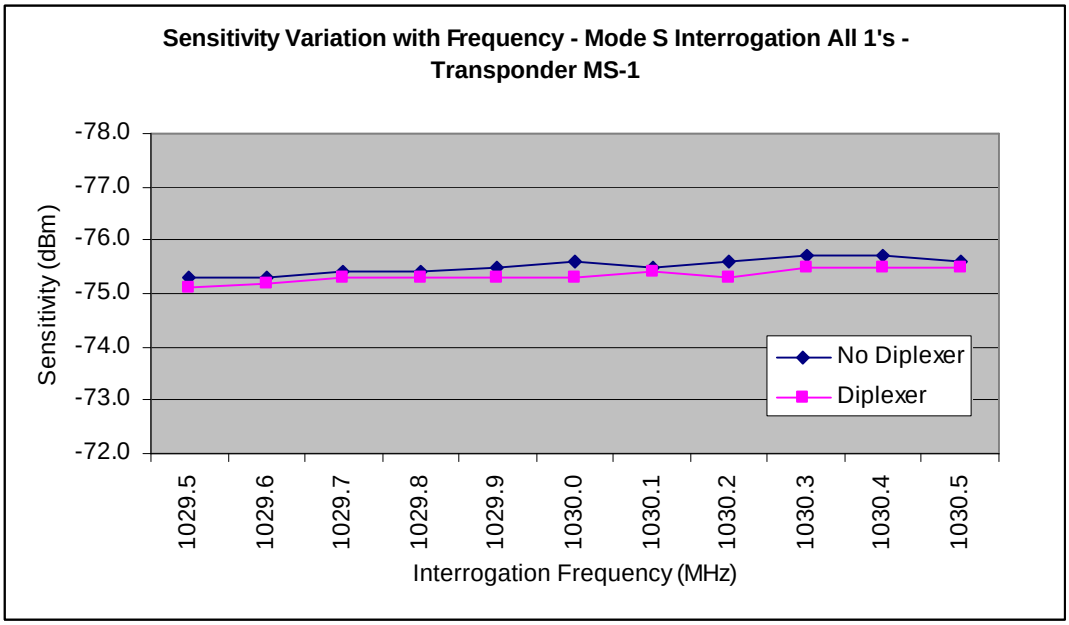

Figure 27A – Sensitivity Variation with Frequency, All 1's Interrogation, Transponder MS-1

Figure 27B shows the Sensitivity Variation with Frequency of transponder MS-1 with a Mode S interrogation using all variable data bits set to binary '0' (again, except for UF and AP fields). This interrogation format will minimize DPSK phase shifts in the interrogation. A subset of the data points was run in this case since the data showed no significant difference between this and the all 1's interrogation format. Subsequent spot checking using the all 0's interrogation with the other two transponders also showed no significant effect from the interrogation data content of the interrogation.

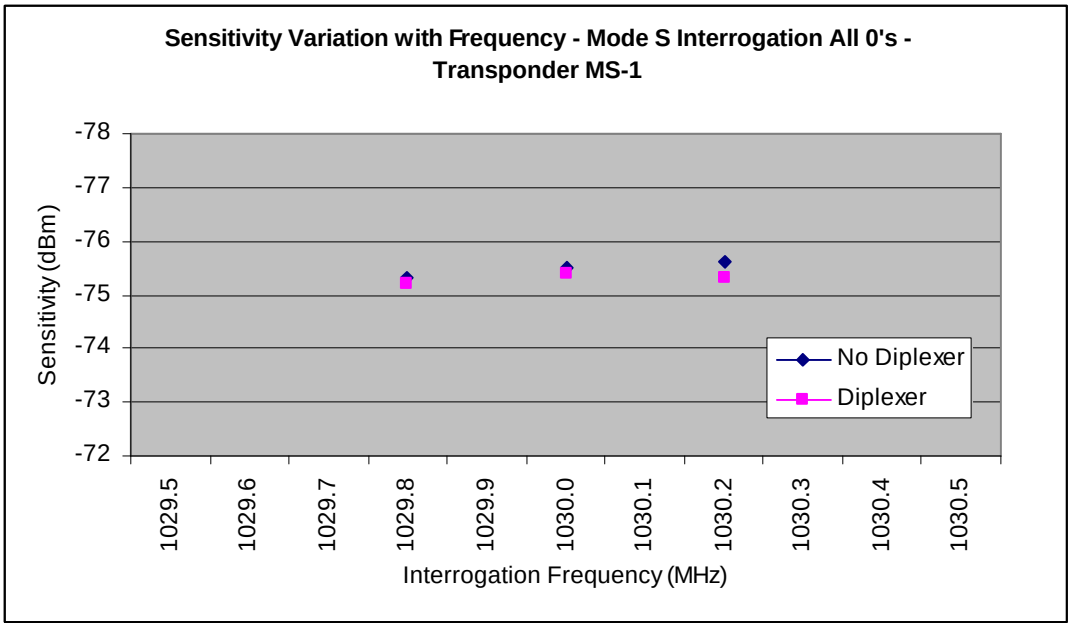

Figure 27B – Sensitivity Variation with Frequency, All 0's Interrogation, Transponder MS-1

Figure 27C shows the Sensitivity Variation with Frequency data from transponder MS-2. The data is similar to transponder MS-1 with a consistent sensitivity offset of 0.3 dBm with no significant variation with frequency.

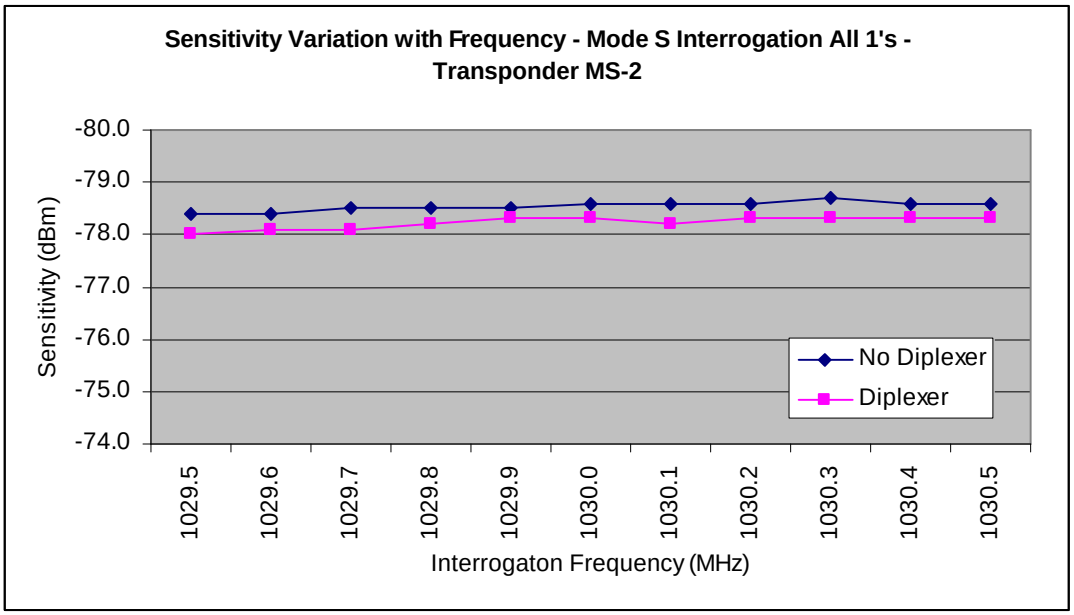

Figure 27C – Sensitivity Variation with Frequency, All 1's Interrogation, Transponder MS-2

Figure 27D shows the Sensitivity Variation with Frequency data from transponder MS-3. The data is similar to that of the other 2 transponders with a consistent sensitivity offset of 0.3 dBm. The data point at frequency 1029.5 MHz does deviate from the others, not because of any direct effect from the Diplexer, but because it is near the edge of the transponders bandwidth for Mode S format interrogations. All three transponders exhibit a Mode S interrogation acceptance band of very close to plus or minus 500 kHz. In the case of transponder MS-3, at 1029.5 MHz the sensitivity is significantly reduced and varies as the test is repeated.

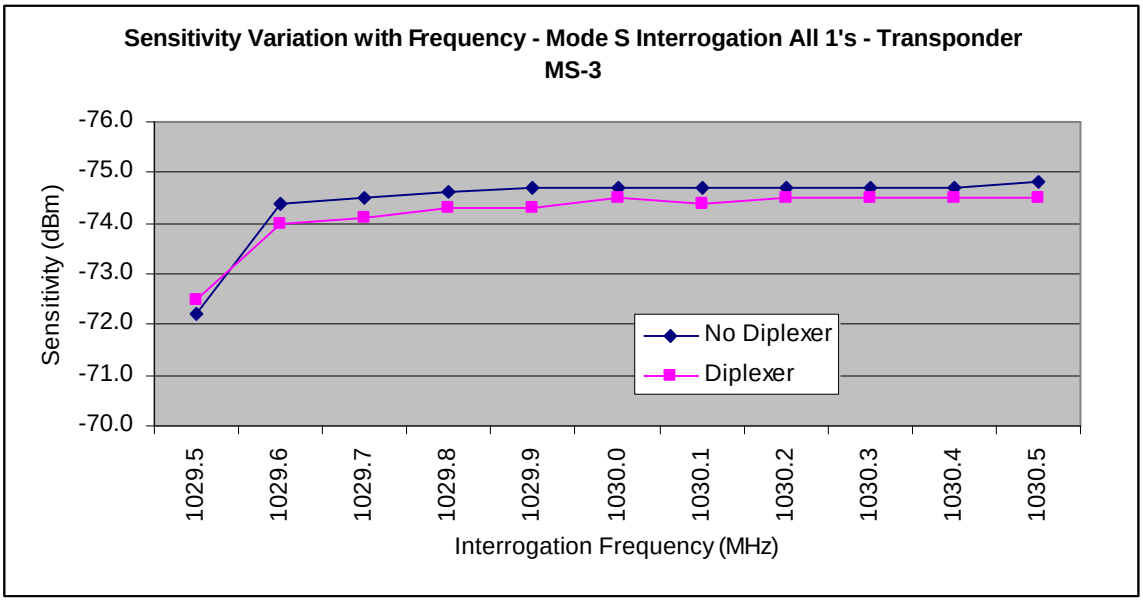

Figure 27D – Sensitivity Variation with Frequency, All 1's Interrogation, Transponder MS-3

The conclusion from running these tests is that there is the expected 0.2 to 0.3 dB reduction in the transponder receiver sensitivity from the Diplexer, but the Mode S sensitivity is not affected as a function of frequency within the operating bandwidth of the transponders.

BANDWIDTH

The transponder's receiver bandwidth with respect to ATCRBS interrogations was measured by varying the interrogation frequency and measuring the receiver sensitivity. The test as defined in RTCA/DO-181C can not be performed with DATAS because it is not able to reach the power level of 60 dB above MTL. Instead the frequencies above and below 1030 MHz where the sensitivity approaches the test limit of about –20 dBm is measured. This range provides about a 50 to 55 dB bandwidth. This is adequate to determine if there is an effect on the transponder bandwidth from the Diplexer. The bandwidth data is presented in the series of graphs from

Figure 28 through Figure 34. There was no significant effect on ATCRBS bandwidth with any of the transponder/Diplexer combinations.

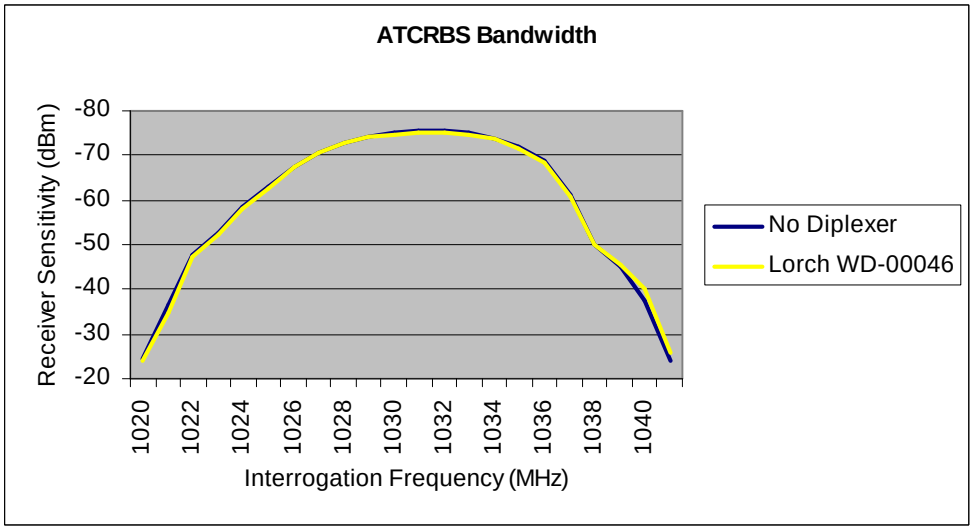

Figure 28 – Receiver Bandwidth, Mode A Interrogation, Transponder MS-1

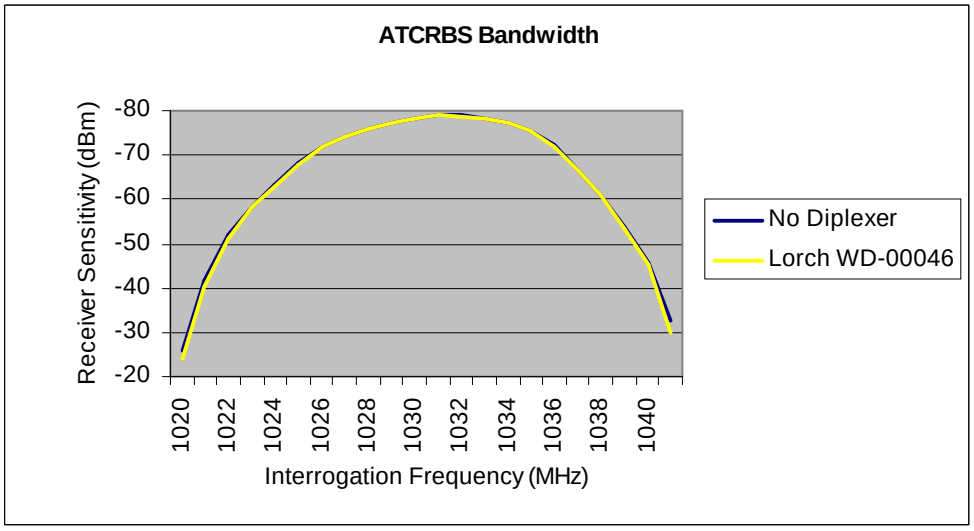

Figure 29 – Receiver Bandwidth, Mode A Interrogation, Transponder MS-2

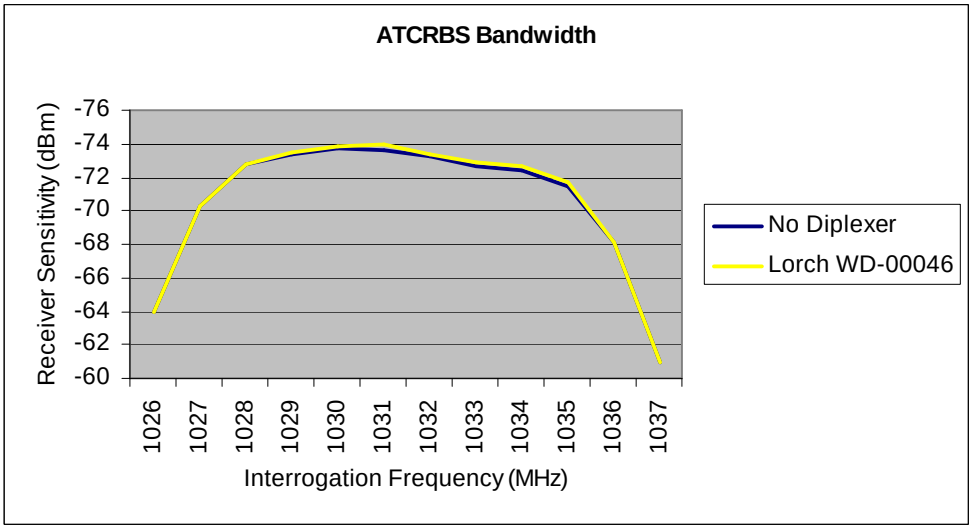

Figure 30 – Receiver bandwidth, Mode A Interrogation, Transponder MS-3

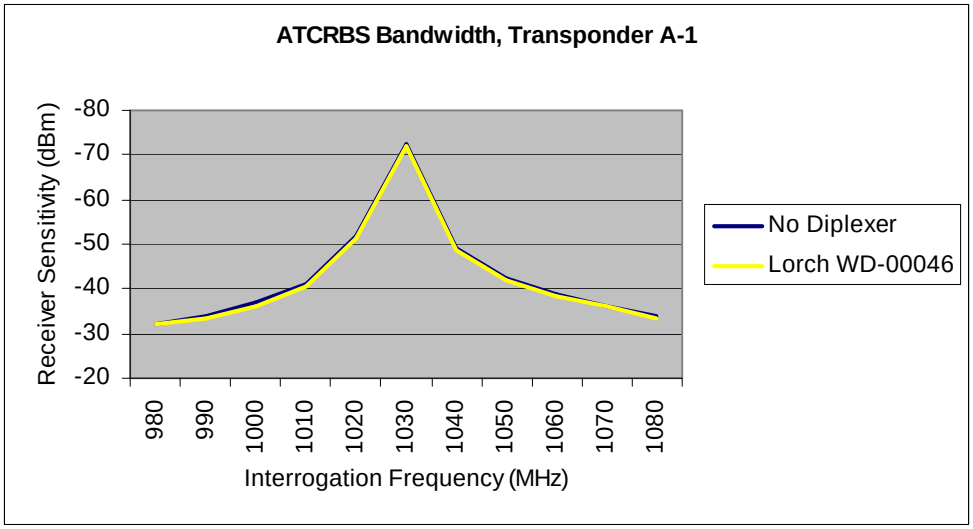

Figure 31 – Receiver Bandwidth, Mode A Interrogation, Transponder A-1

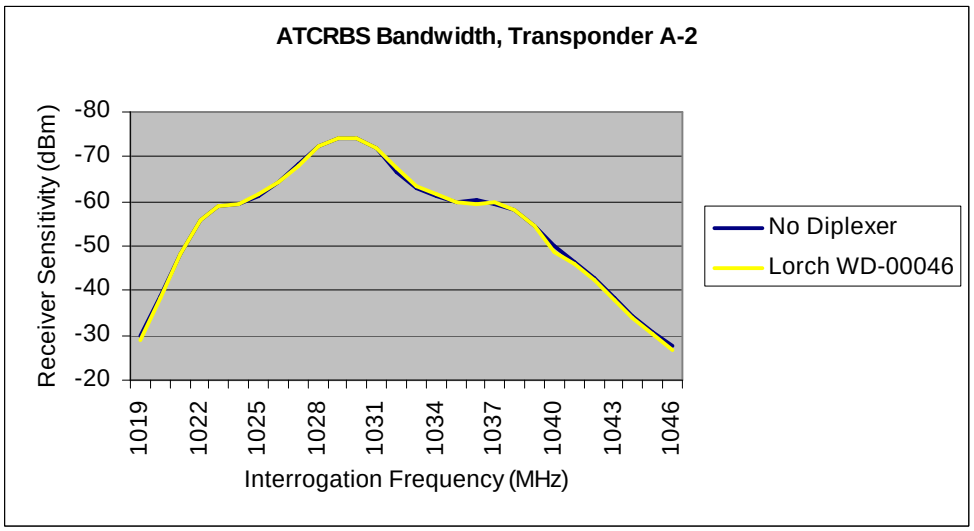

Figure 32 – Receiver Bandwidth, Mode A Interrogation, Transponder A-2

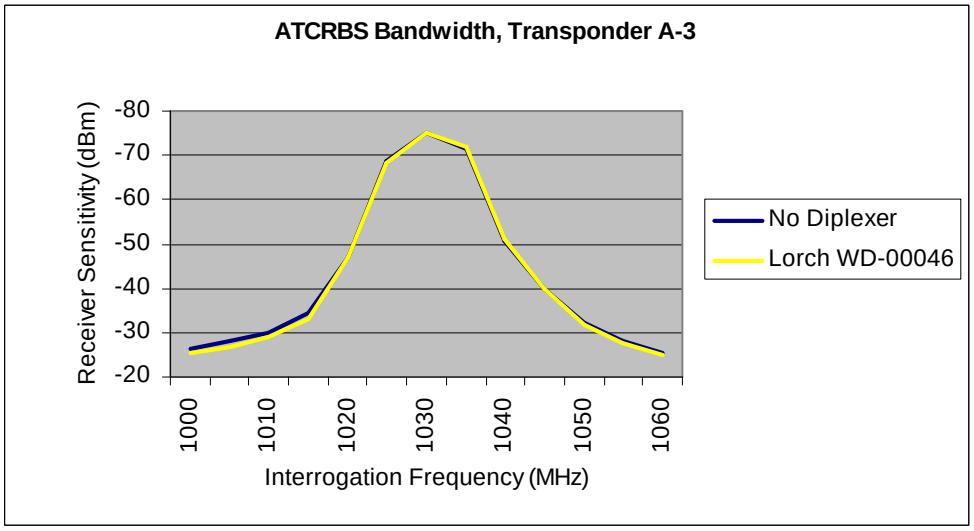

Figure 33 – Receiver Bandwidth, Mode A Interrogation, Transponder A-3

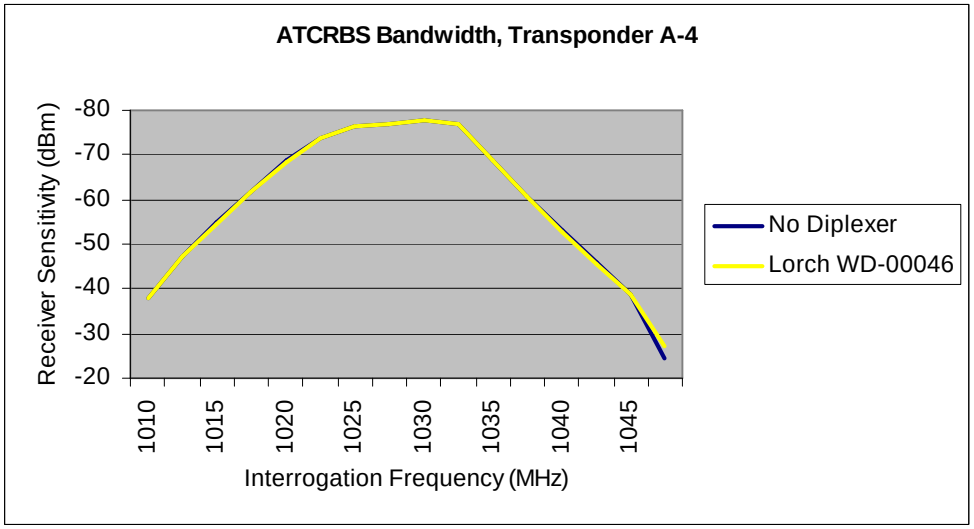

Figure 34 – Receiver Bandwidth, Mode A Interrogation, Transponder A-4

MODE A/C PULSE POSITION TOLERANCE

The transponder is required to accept the pulse position of ATCRBS interrogations as valid if the spacing between P1 and P3 is within plus or minus 0.2 microseconds of the nominal spacing. The transponder is required to reject the pulse position of ATCRBS interrogations if the spacing between P1 and P3 differs from nominal by 1.0 microsecond or more. Tests were conducted to determine if the P1 and P3 spacing tolerance for modes A and C interrogations are affected by a Diplexer installation. Figures 35 through 48 show that there was no effect on mode A or mode C pulse spacing tolerance.

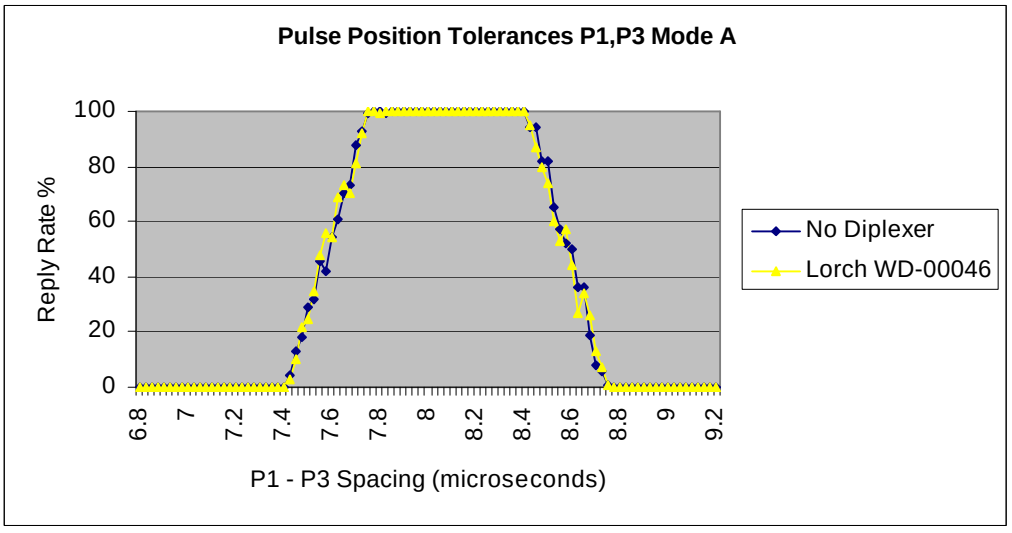

Figure 35 – Mode A P1 – P3 Pulse Position Tolerance, Transponder MS-1

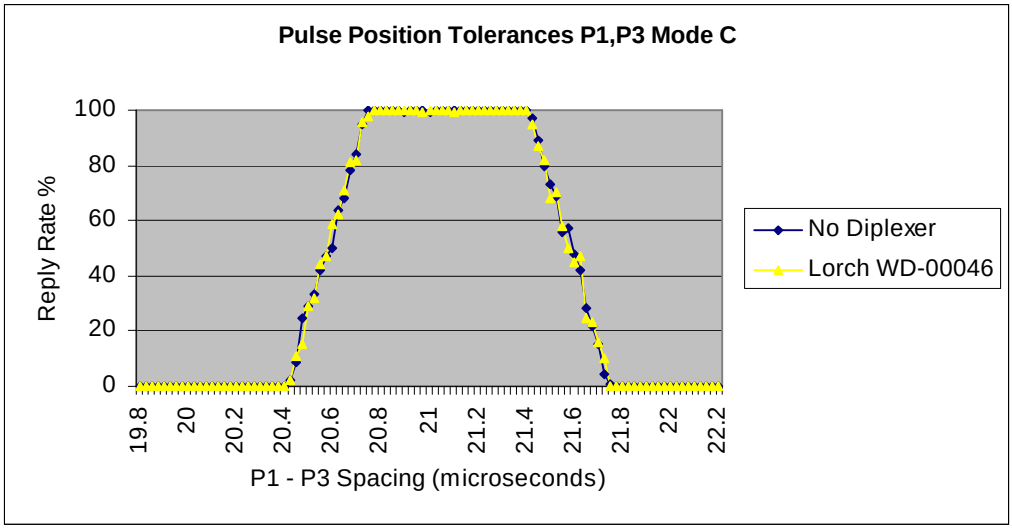

Figure 36 – Mode C P1 – P3 Pulse Position Tolerance, Transponder MS-1

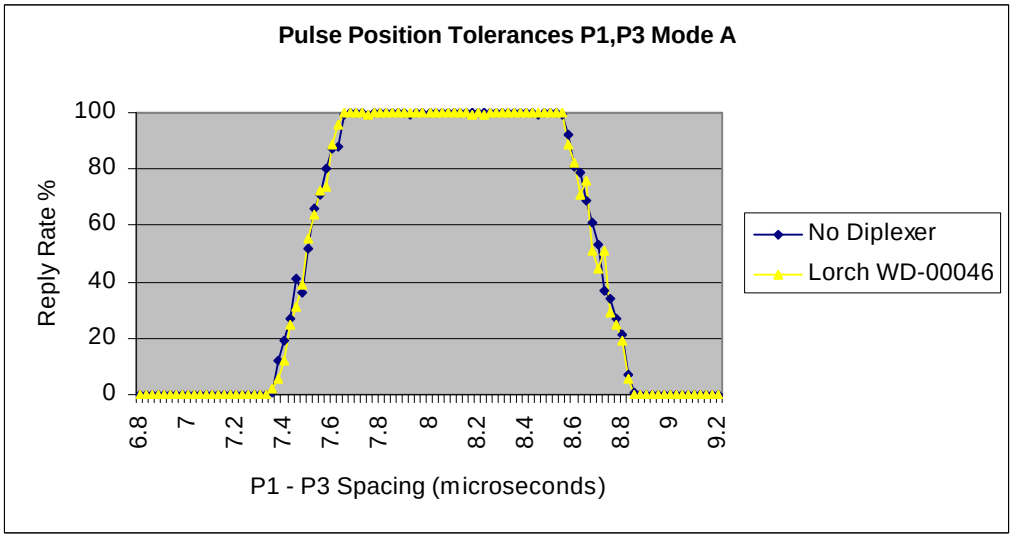

Figure 37 – Mode A P1 – P3 Pulse Position Tolerance, Transponder MS-2

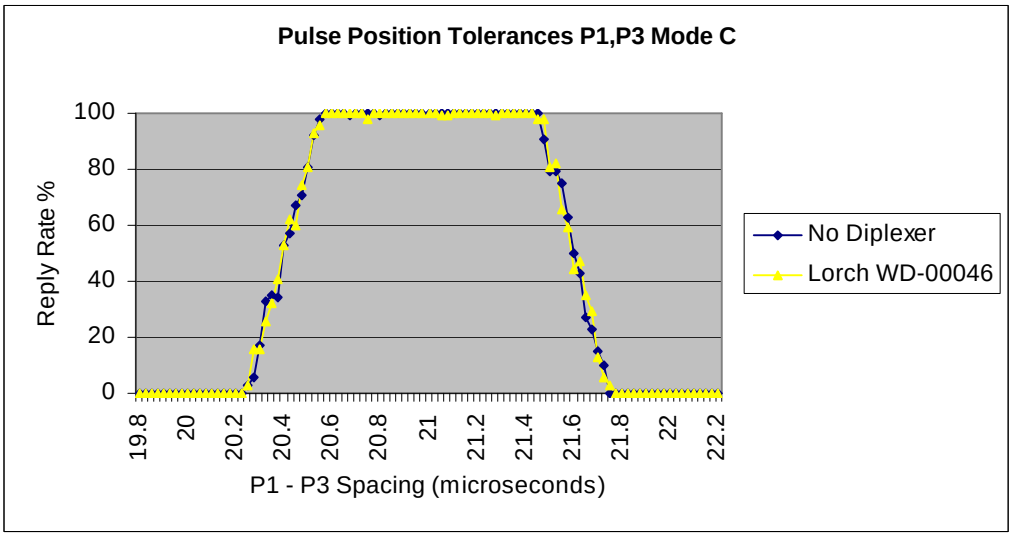

Figure 38 – Mode C P1 – P3 Pulse Position Tolerance, Transponder MS-2

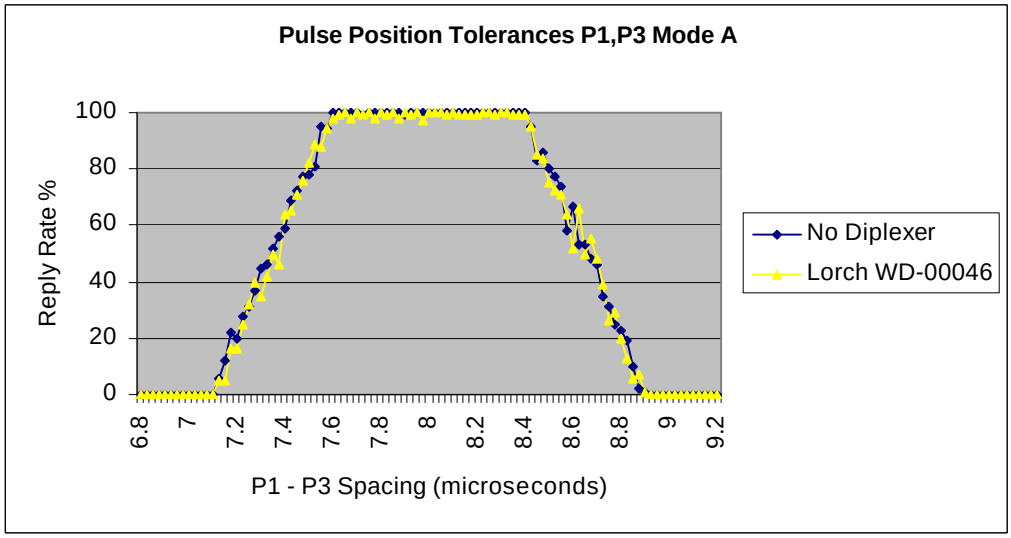

Figure 39 – Mode A P1 – P3 Pulse Position Tolerance, Transponder MS-3

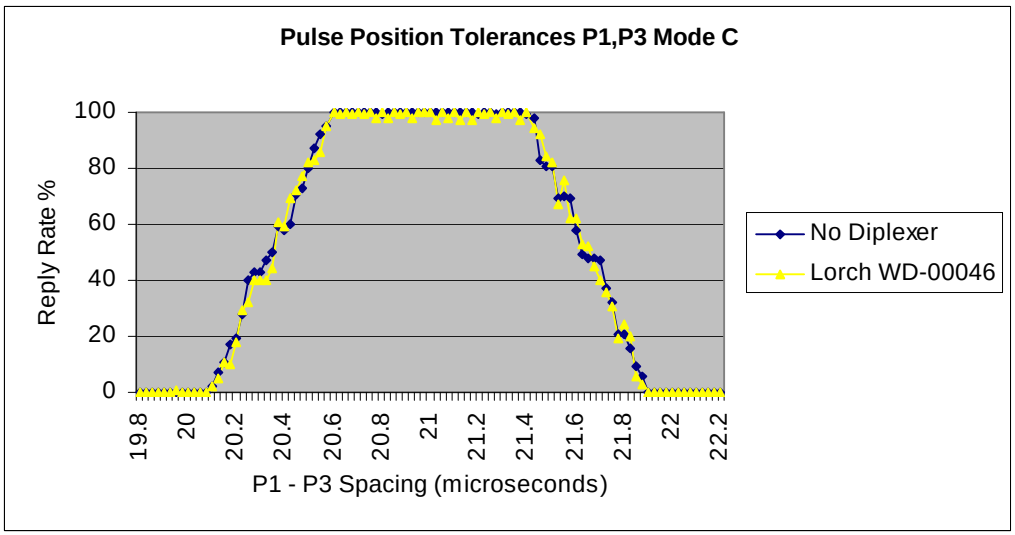

Figure 40 – Mode C P1 – P3 Pulse Position Tolerance, Transponder MS-3

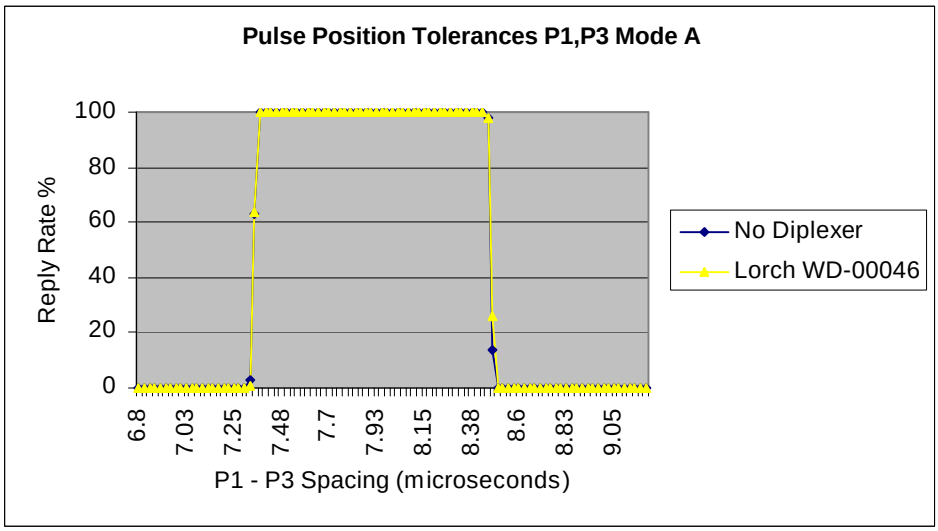

Figure 41 – Mode A P1 – P3 Pulse Position Tolerance, Transponder A-1

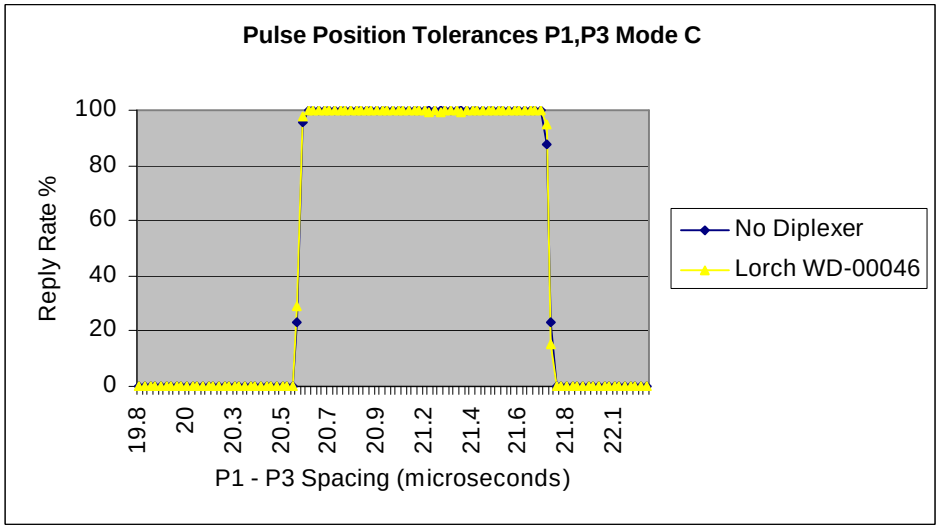

Figure 42 – Mode C P1 – P3 Pulse Position Tolerance, Transponder A-1

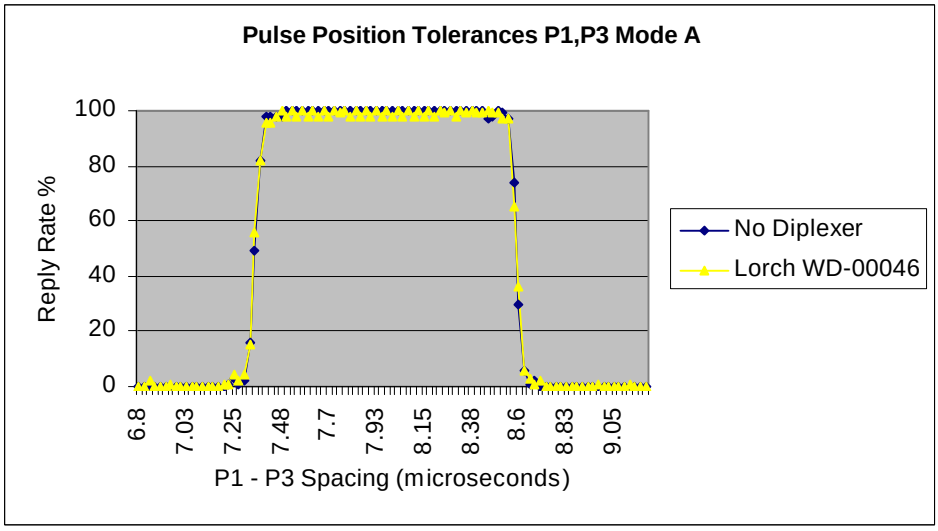

Figure 43 – Mode A P1 – P3 Pulse Position Tolerance, Transponder A-2

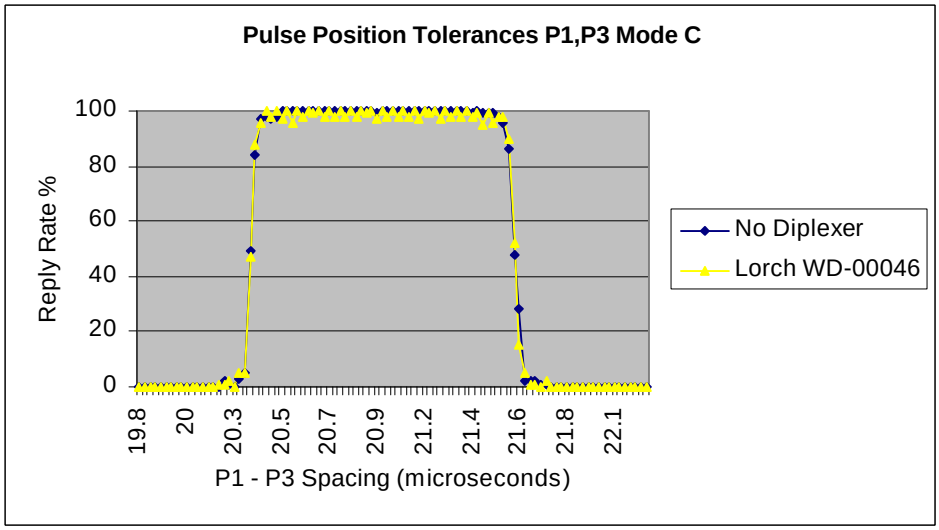

Figure 44 – Mode C P1 – P3 Pulse Position Tolerance, Transponder A-2

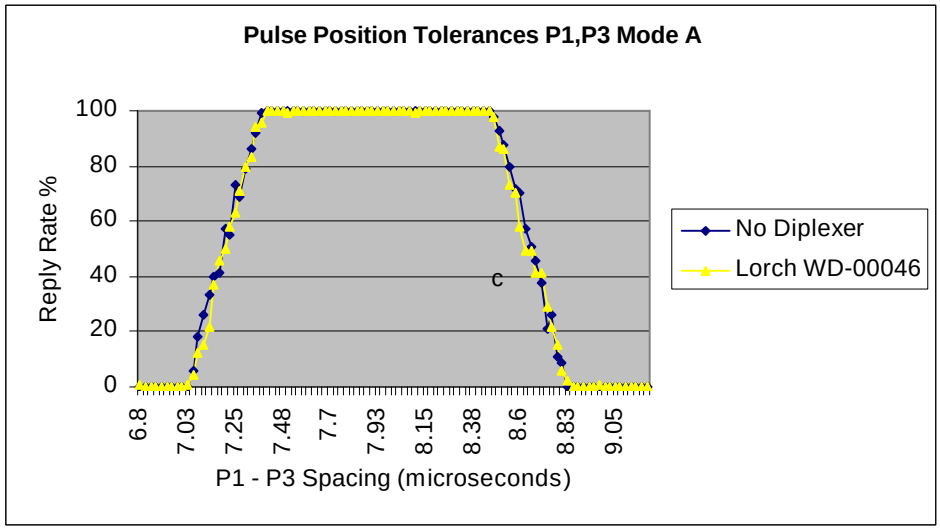

Figure 45 – Mode A P1 – P3 Pulse Position Tolerance, Transponder A-3

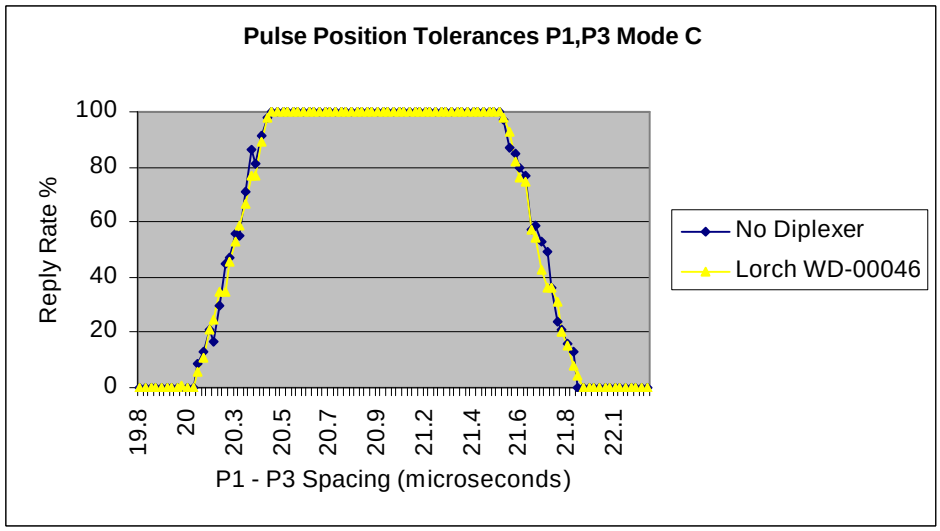

Figure 46 – Mode C P1 – P3 Pulse Position Tolerance, Transponder A-3

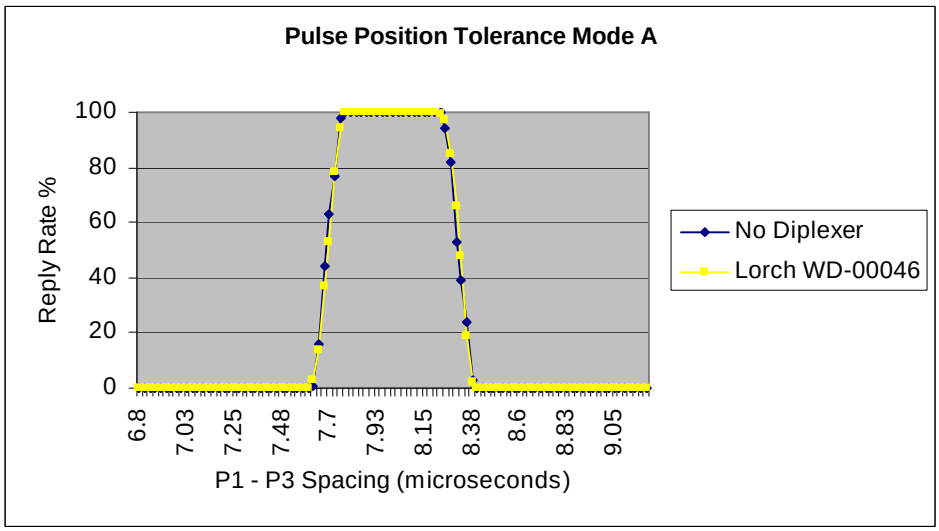

Figure 47 – Mode A P1 – P3 Pulse Position Tolerance, Transponder A-4

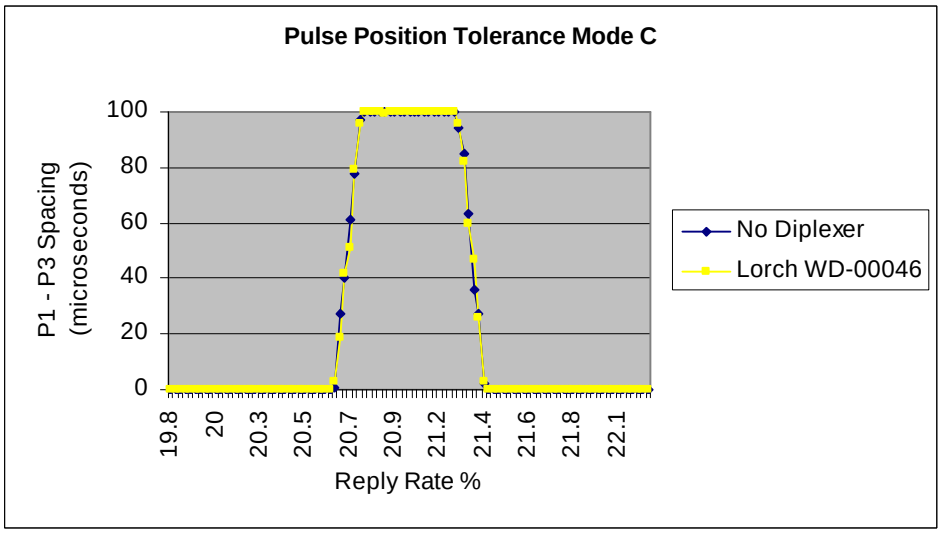

Figure 48 – Mode C P1 – P3 Pulse Position Tolerance, Transponder A-4

ATCRBS/MODE S PULSE POSITION TOLERANCE P1 – P3

The transponder is required to accept the pulse position of ATCRBS/Mode S interrogations as valid if the spacing between P1 and P3 is within plus or minus 0.2 microseconds of the nominal spacing. The transponder is required to reject the pulse position of ATCRBS/Mode S interrogations if the spacing between P1 and P3 differs from nominal by 1.0 microsecond or more. Tests were conducted to determine if the P1 and P3 spacing tolerance for ATCRBS/Mode S interrogations are affected by a Diplexer installation. Figures 49 through 54 show that there was no effect on ATCRBS/Mode S P1 – P3 pulse spacing tolerance.

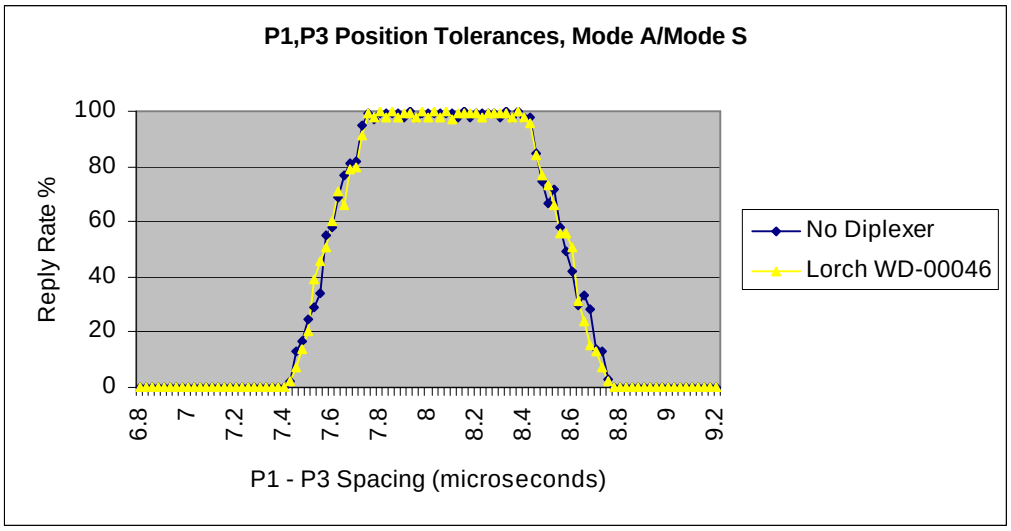

Figure 49 – ATCRBS/Mode S (Mode A) P1 – P3 Pulse Position Tolerance, Transponder MS-1

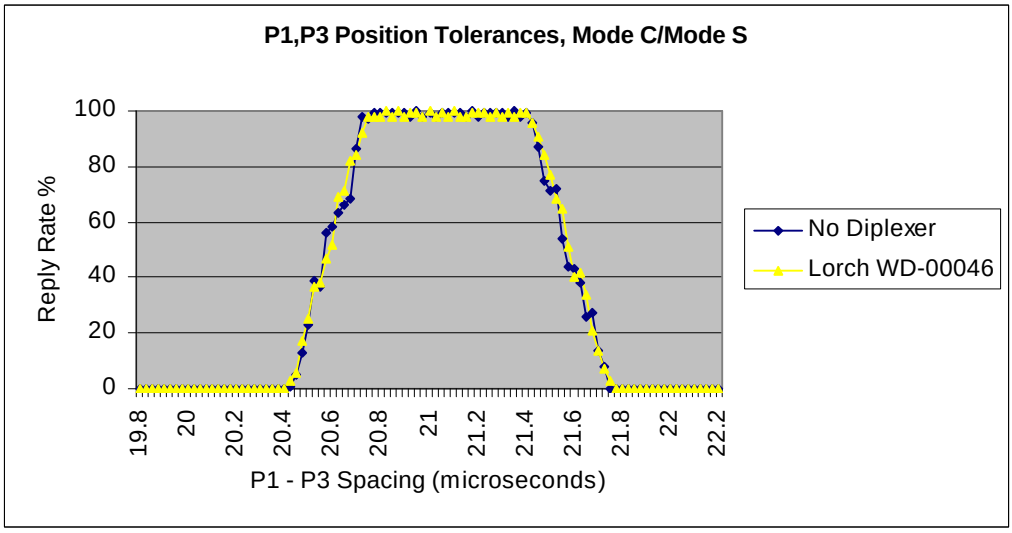

Figure 50 – ATCRBS/Mode S (Mode C) P1 – P3 Pulse Position Tolerance, Transponder MS-1

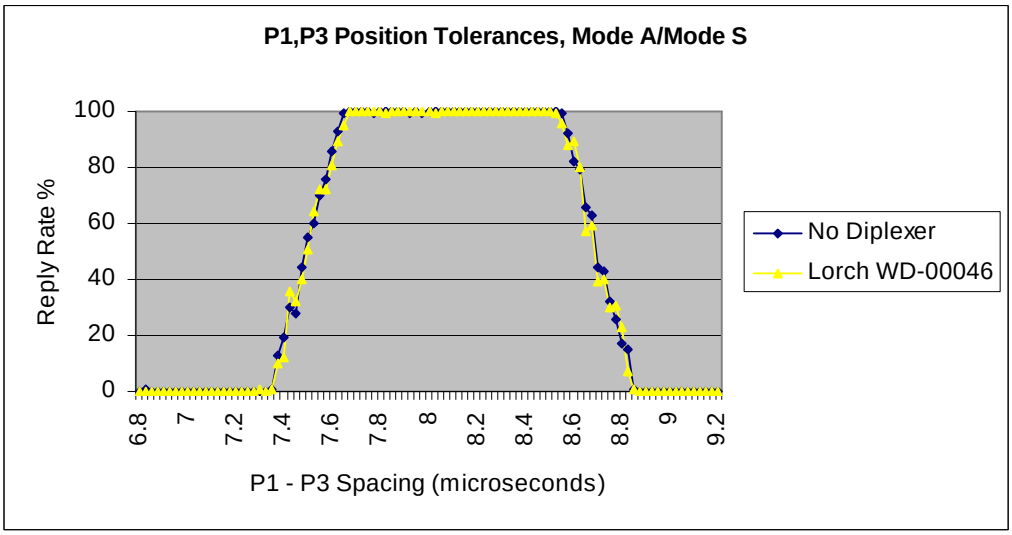

Figure 51 – ATCRBS/Mode S (Mode A) P1 – P3 Pulse Position Tolerance, Transponder MS-2

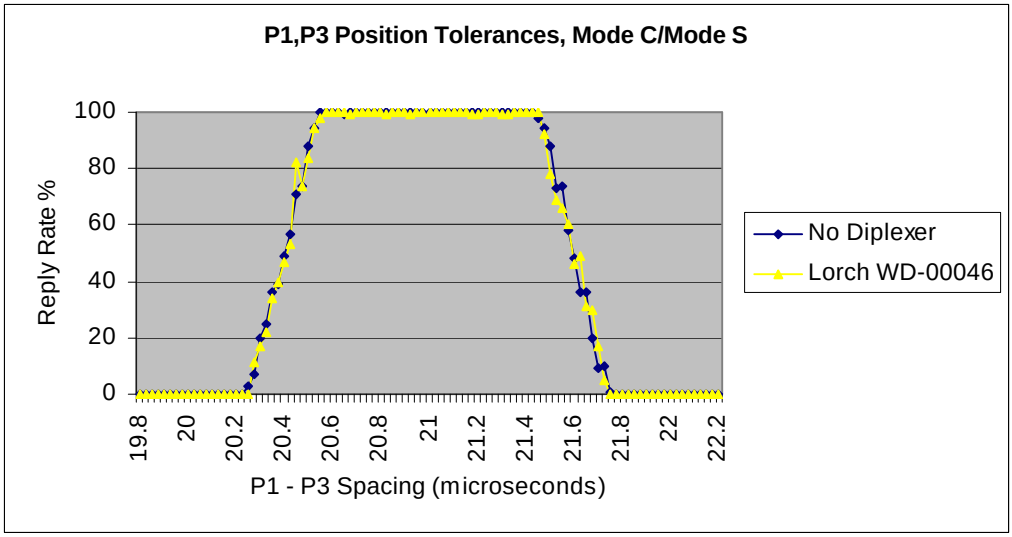

Figure 52 – ATCRBS/Mode S (Mode C) P1 – P3 Pulse Position Tolerance, Transponder MS-2

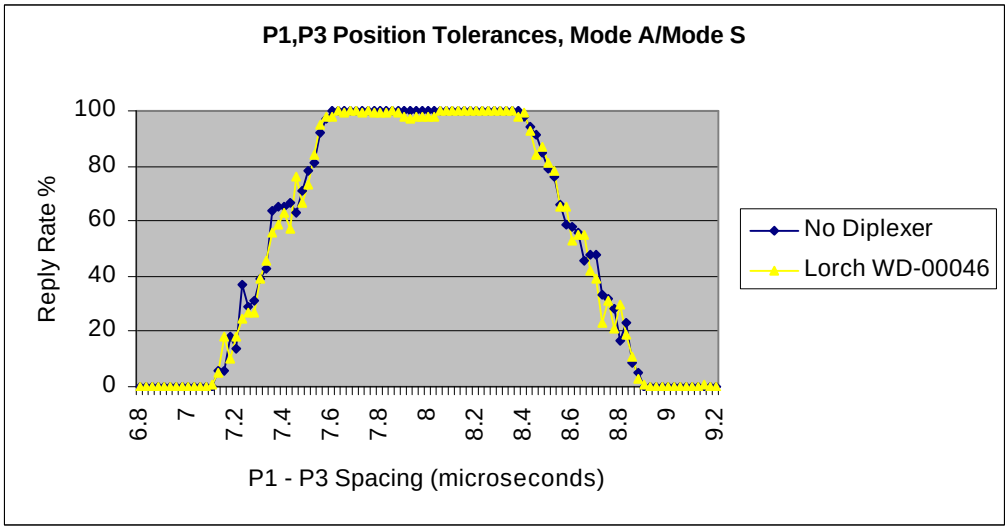

Figure 53 – ATCRBS/Mode S (Mode A) P1 – P3 Pulse Position Tolerance, Transponder MS-3

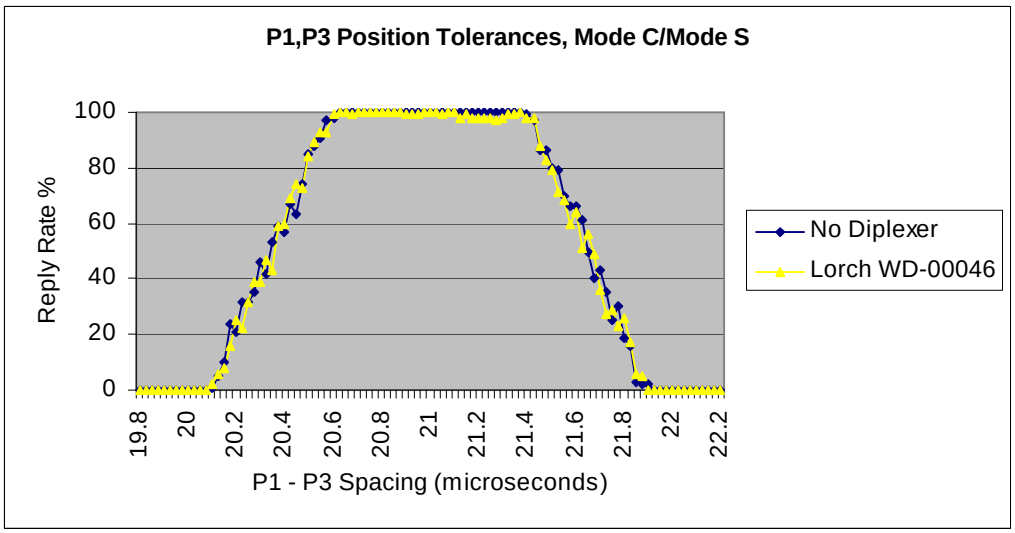

Figure 54 – ATCRBS/Mode S (Mode C) P1 – P3 Pulse Position Tolerance, Transponder MS-3

ATCRBS/MODE S PULSE POSITION TOLERANCE P3 – P4

The transponder is required to accept the pulse position of ATCRBS/Mode S interrogations as valid if the spacing between P3 and P4 is within plus or minus 0.05 microseconds of the nominal spacing. The transponder is required to reject the pulse position of ATCRBS/Mode S interrogations if the spacing between P3 and P4 differs from nominal by more than 0.3 microseconds. Tests were conducted to determine if the P3 and P4 spacing tolerance for ATCRBS/Mode S interrogations are affected by a Diplexer installation. Figures 55 through 60 show that there was no effect on ATCRBS/Mode S P3 – P4 pulse spacing tolerance.

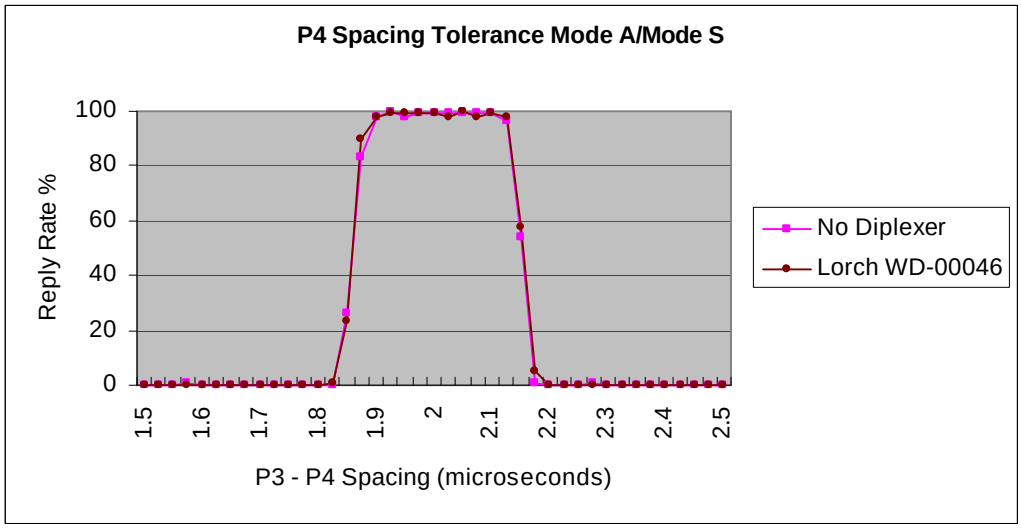

Figure 55 – ATCRBS/Mode S (Mode A) P3 – P4 Pulse Position Tolerance, Transponder MS-1

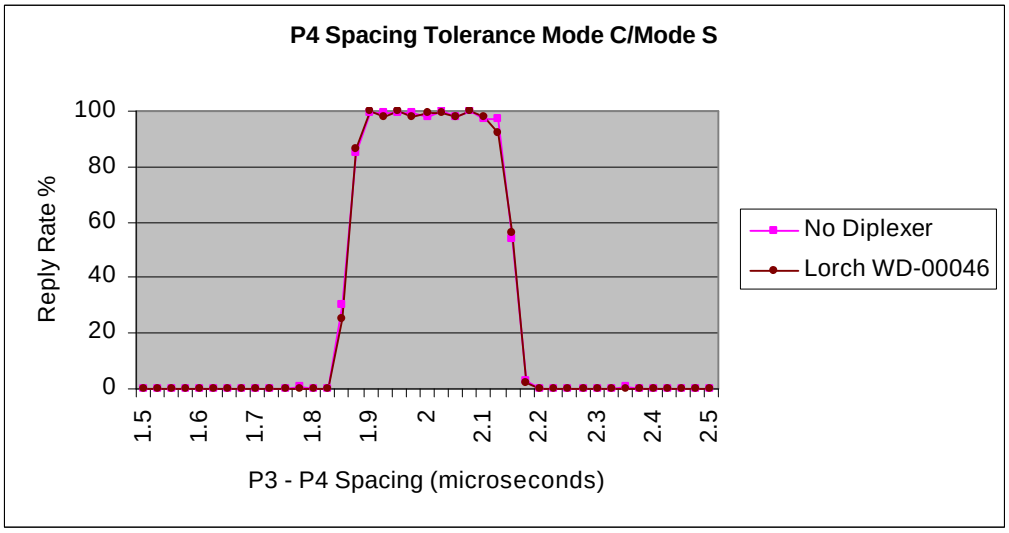

Figure 56 – ATCRBS/Mode S (Mode C) P3 – P4 Pulse Position Tolerance, Transponder MS-1

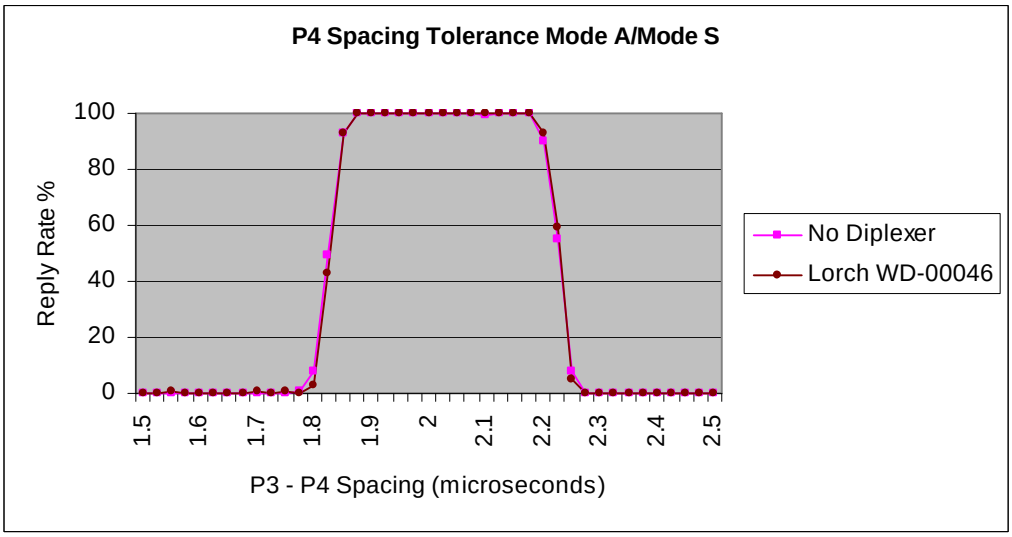

Figure 57 – ATCRBS/Mode S (Mode A) P3 – P4 Pulse Position Tolerance, Transponder MS-2

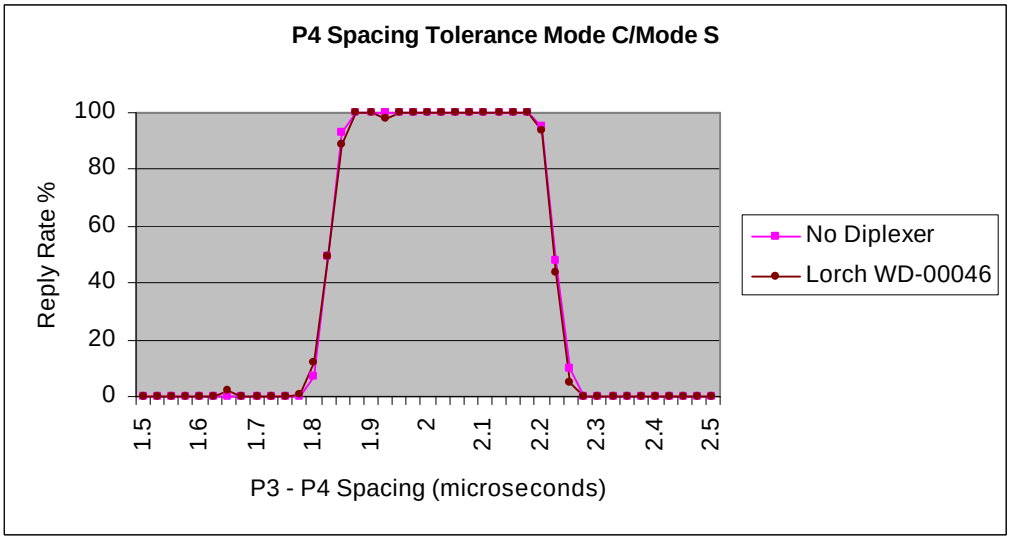

Figure 58 – ATCRBS/Mode S (Mode C) P3 – P4 Pulse Position Tolerance, Transponder MS-2

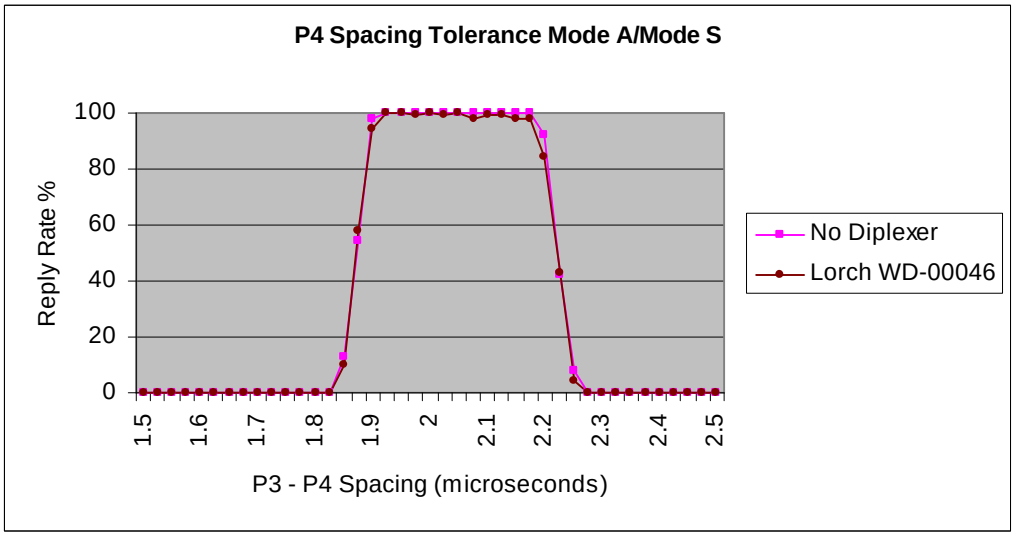

Figure 59 – ATCRBS/Mode S (Mode A) P3 – P4 Pulse Position Tolerance, Transponder MS-3

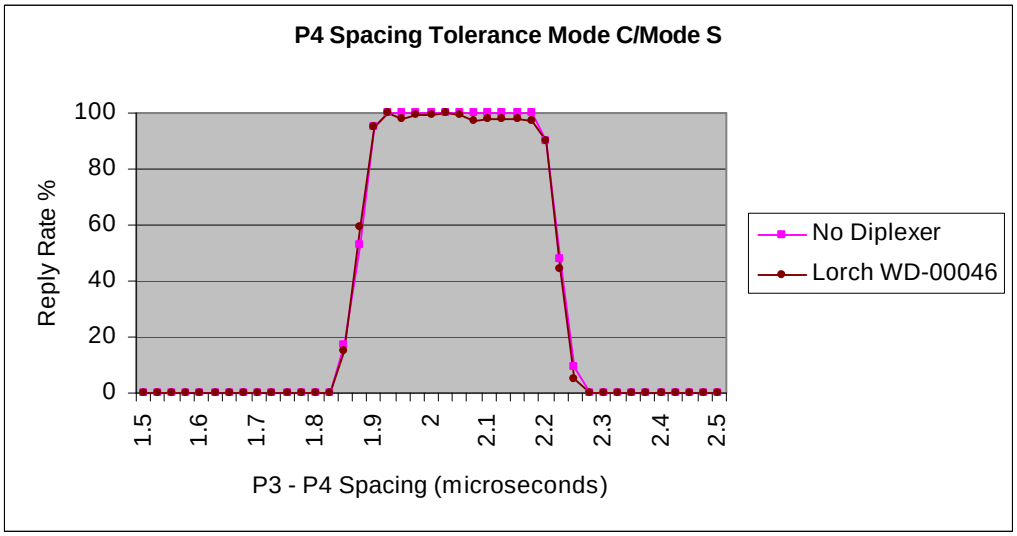

Figure 60 – ATCRBS/Mode S (Mode C) P3 – P4 Pulse Position Tolerance, Transponder MS-3

PULSE DURATION TOLERANCES, ATCRBS

The transponder is required to accept an interrogation as valid if the duration of both P1 and P3 pulses are between 0.7 and 0.9 microseconds. The transponder is required to reply to no more than 10 percent of interrogations that have either P1 or P3 pulses less than 0.3 microseconds. Tests were conducted on the transponders in each configuration to determine if the Diplexers have an effect on pulse duration tolerance. The tests were conducted using both a Mode A and a Mode C interrogation type. The results are nearly identical for the two modes, so to avoid redundancy, only the Mode A plots are presented. The data presented in Figures 61 through 74 show that there is no effect.

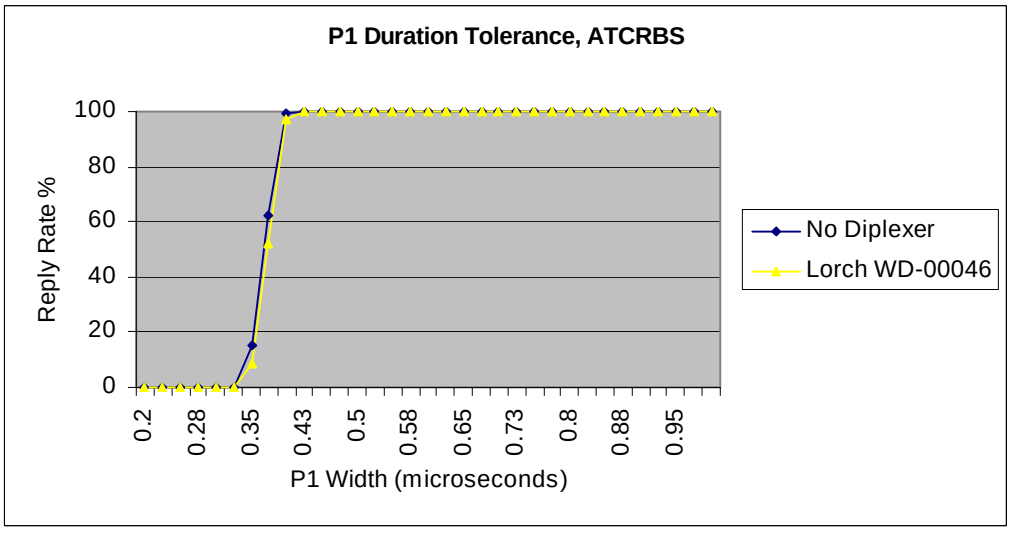

Figure 61 – ATCRBS P1 Pulse Duration Tolerance, Transponder MS-1

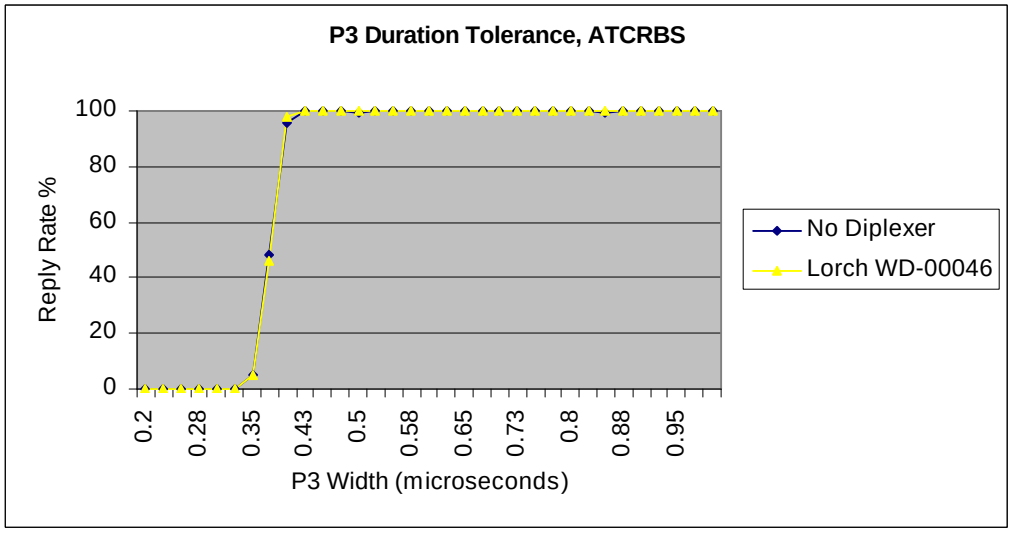

Figure 62 – ATCRBS P3 Pulse Duration Tolerance, Transponder MS-1

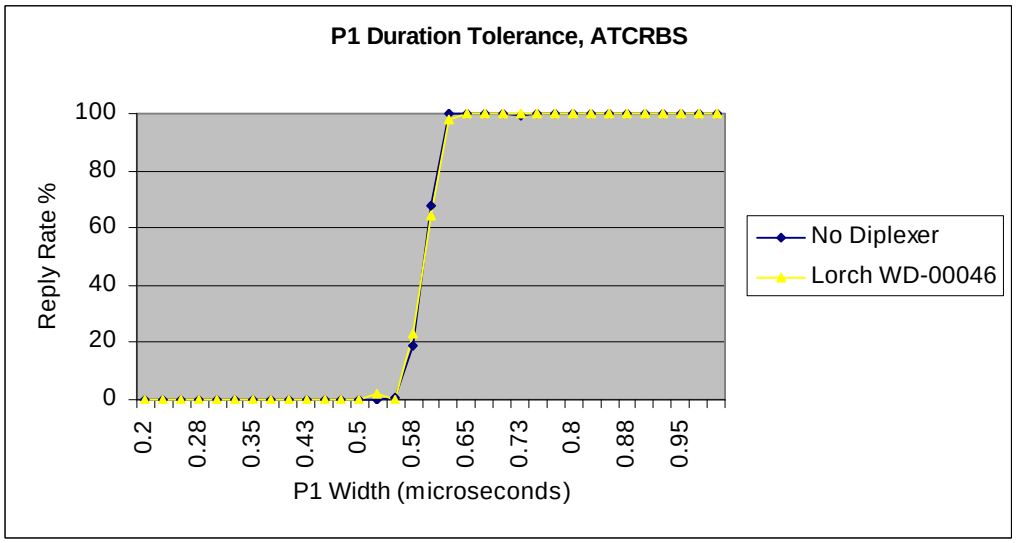

Figure 63 – ATCRBS P1 Pulse Duration Tolerance, Transponder MS-2

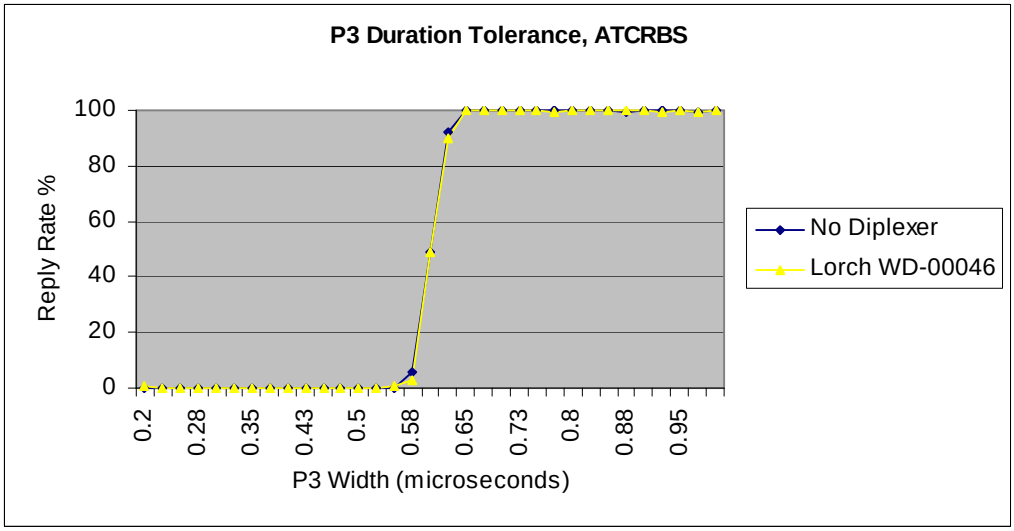

Figure 64 – ATCRBS P3 Pulse Duration Tolerance, Transponder MS-2

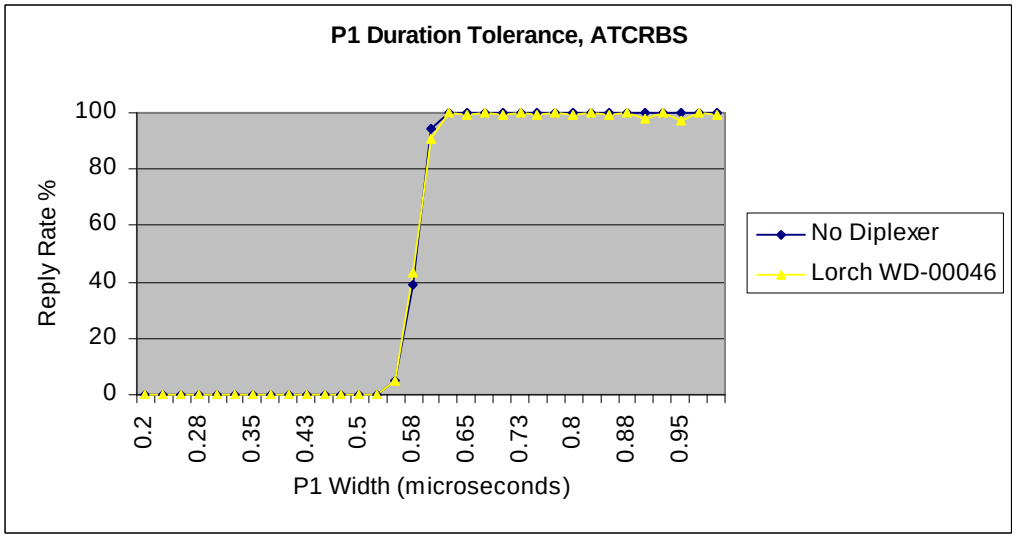

Figure 65 – ATCRBS P1 Pulse Duration Tolerance, Transponder MS-3

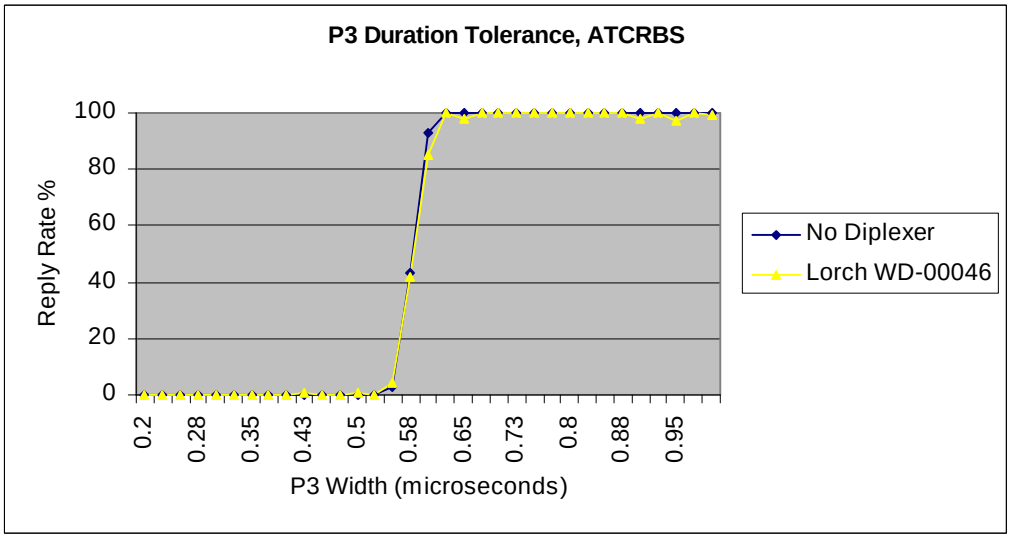

Figure 66 – ATCRBS P3 Pulse Duration Tolerance, Transponder MS-3

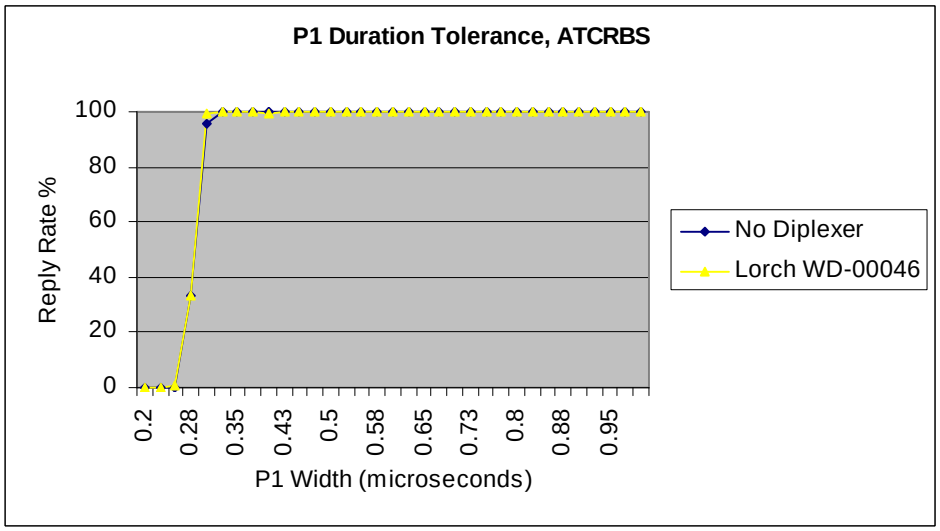

Figure 67 – ATCRBS P1 Pulse Duration Tolerance, Transponder A-1

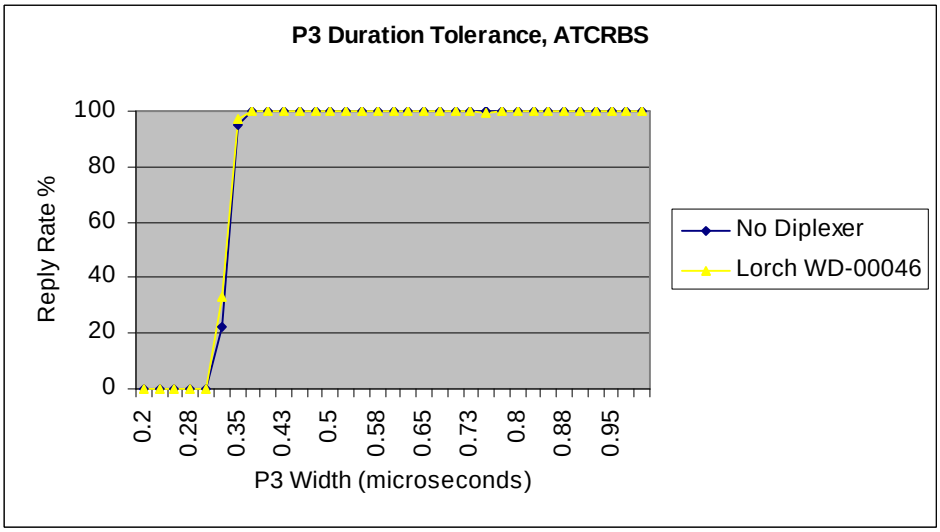

Figure 68 – ATCRBS P3 Pulse Duration Tolerance, Transponder A-1

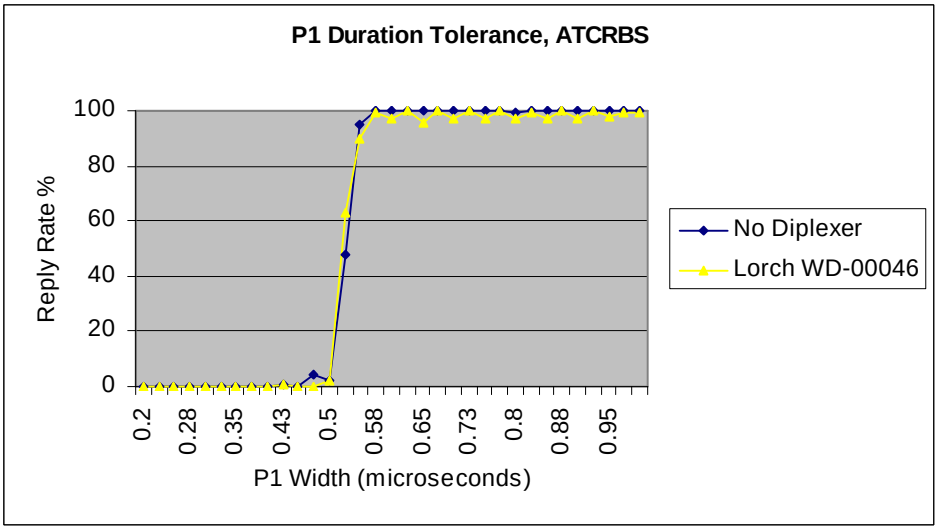

Figure 69 – ATCRBS P1 Pulse Duration Tolerance, Transponder A-2

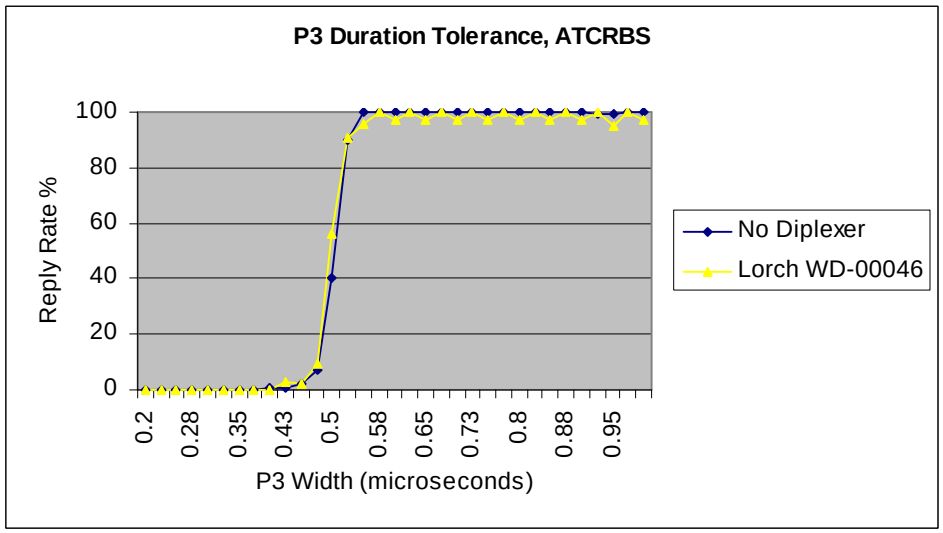

Figure 70 – ATCRBS P3 Pulse Duration Tolerance, Transponder A-2

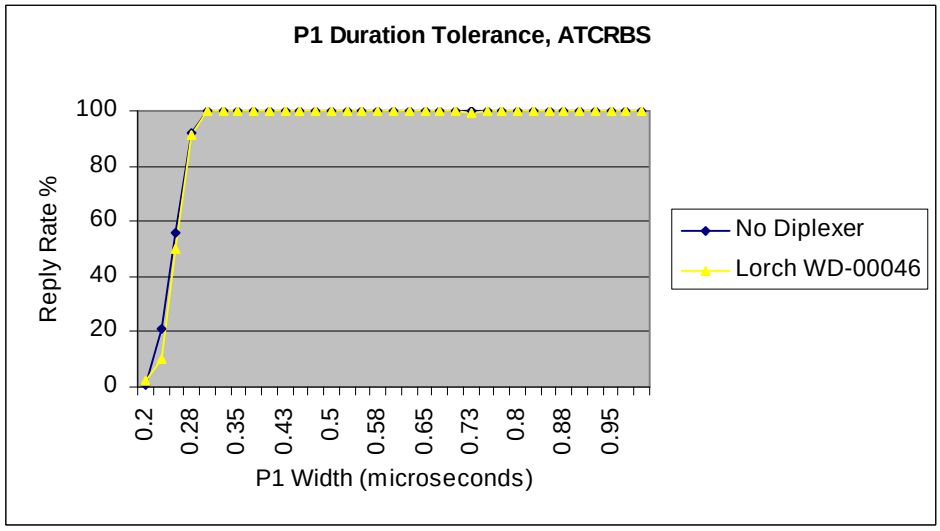

Figure 71 – ATCRBS P1 Pulse Duration Tolerance, Transponder A-3

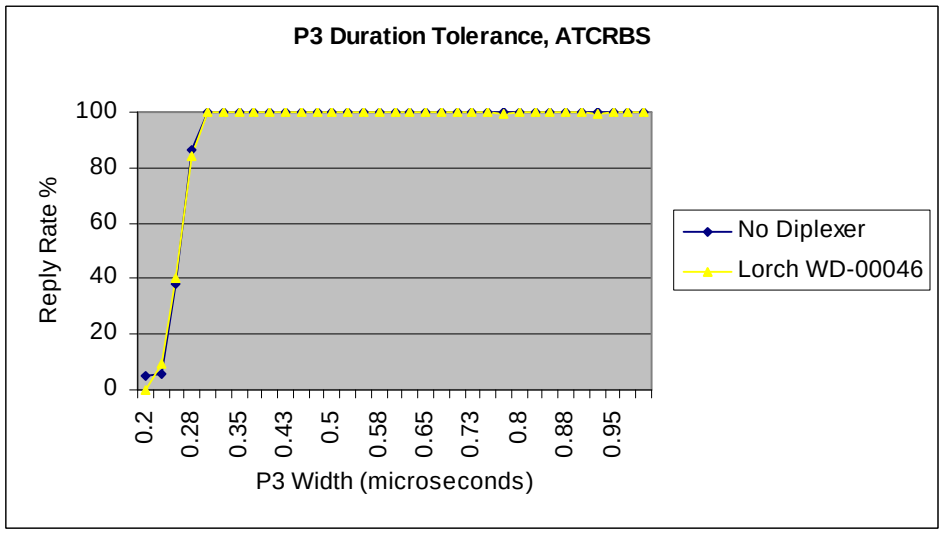

Figure 72 – ATCRBS P3 Pulse Duration Tolerance, Transponder A-3

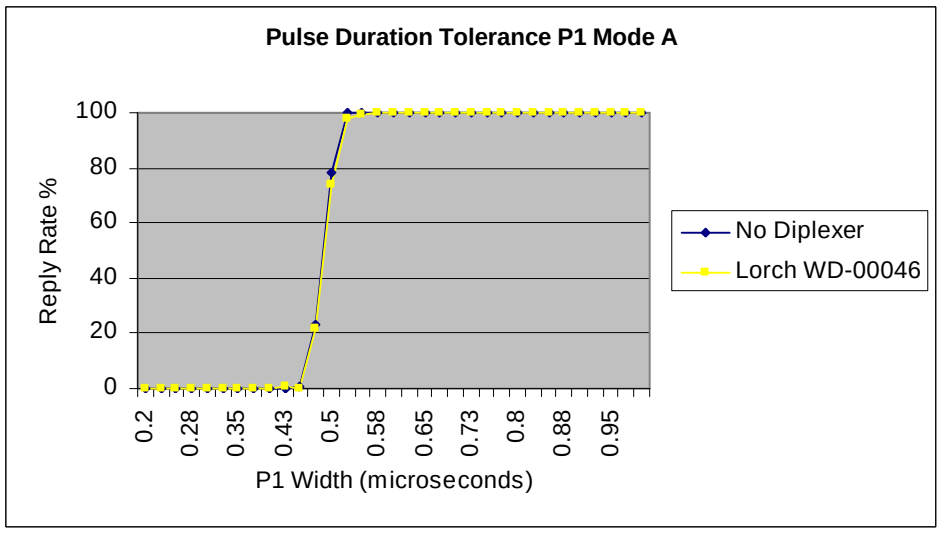

Figure 73 – ATCRBS P1 Pulse Duration Tolerance, Transponder A-4

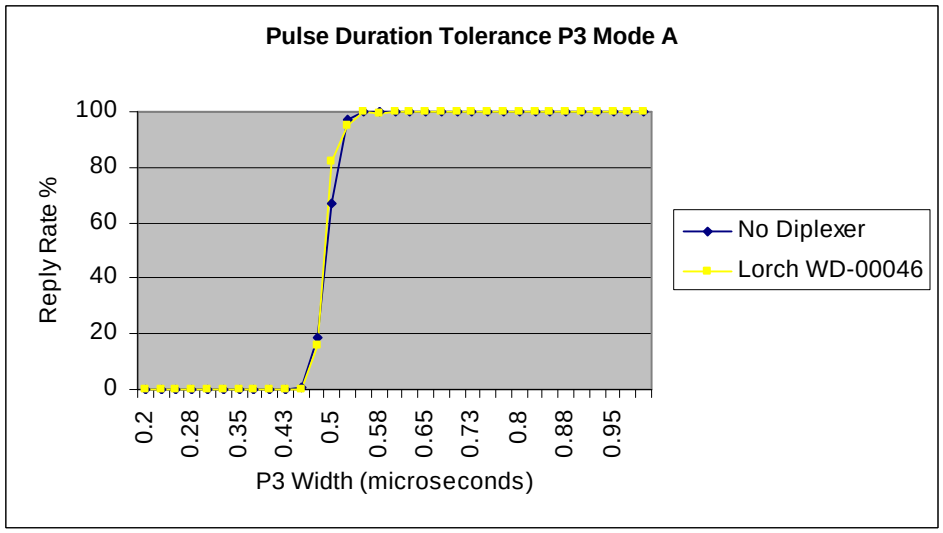

Figure 74 – ATCRBS P3 Pulse Duration Tolerance, Transponder A-4

PULSE DURATION TOLERANCES, ATCRBS/MODE S

The transponder is required to accept an ATCRBS/Mode S interrogation as valid if the duration of both P1 and P3 pulses are between 0.7 and 0.9 microseconds and the duration of P4 is between 1.5 and 1.7 microseconds. The transponder is required to reply to no more than 10 percent of interrogations that have either P1 or P3 pulses less than 0.3 microseconds. The transponder must not accept an interrogation if the P4 duration is outside the range between 1.2 and 2.5 microseconds. Tests were conducted on the transponders in each configuration to determine if the Diplexers have an effect on pulse duration tolerance. The tests were conducted using both a Mode A and a Mode C ATCRBS/Mode S interrogation types. The results are nearly identical for the two modes, so to avoid redundancy, only the Mode A/Mode S plots are presented. The data presented in Figures 75 through 83 show that there is no effect.

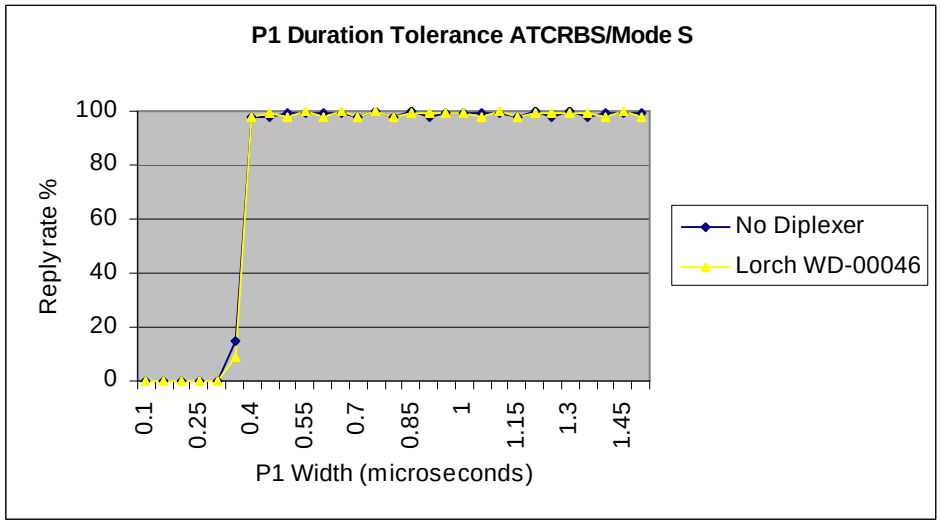

Figure 75 – ATCRBS/Mode S P1 Pulse Duration Tolerance, Transponder MS-1

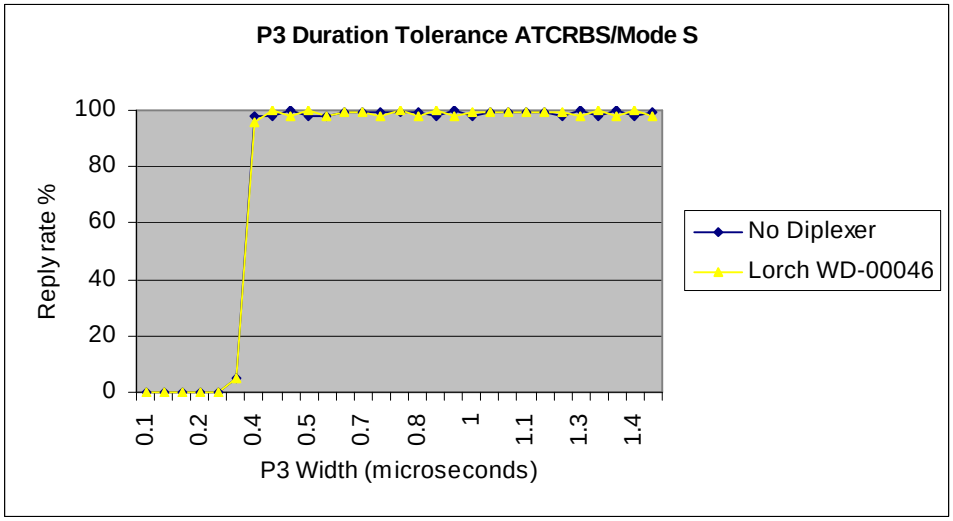

Figure 76 – ATCRBS/Mode S P3 Pulse Duration Tolerance, Transponder MS-1

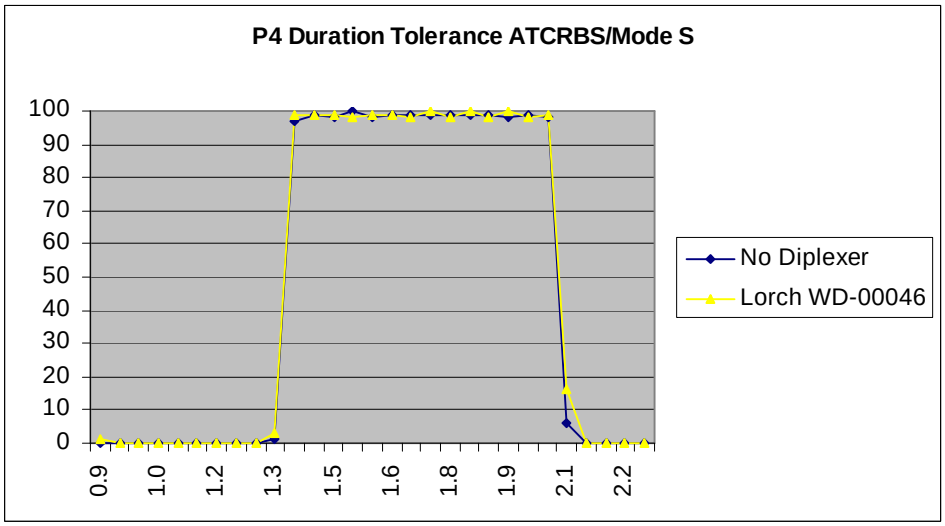

Figure 77 – ATCRBS/Mode S P4 Pulse Duration Tolerance, Transponder MS-1

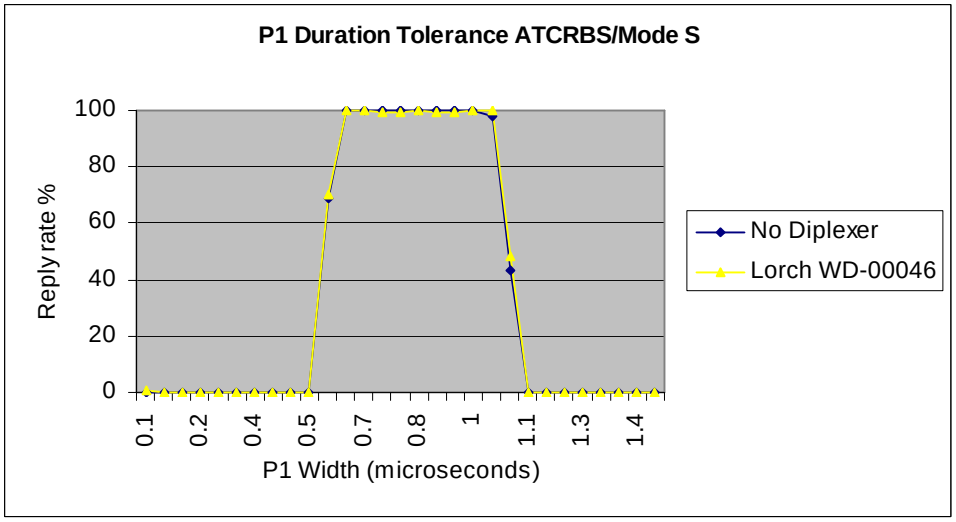

Figure 78 – ATCRBS/Mode S P1 Pulse Duration Tolerance, Transponder MS-2

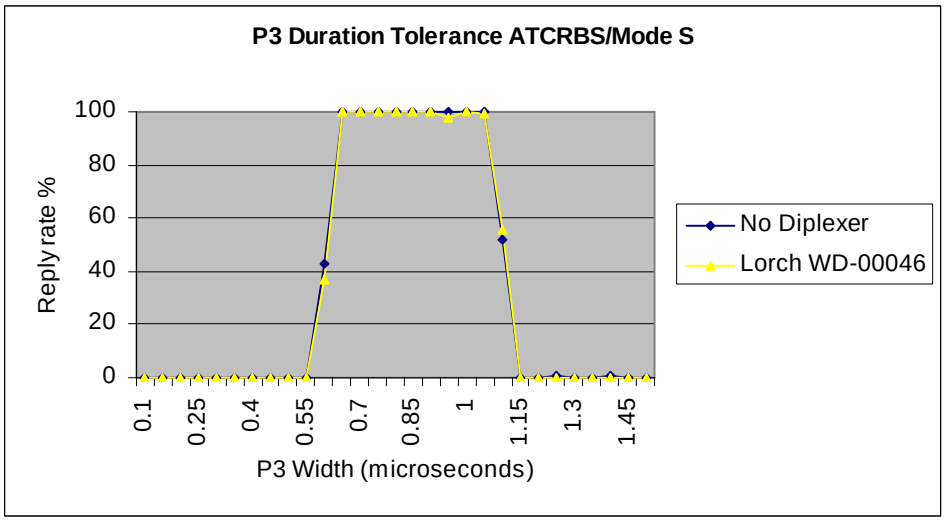

Figure 79 – ATCRBS/Mode S P3 Pulse Duration Tolerance, Transponder MS-2

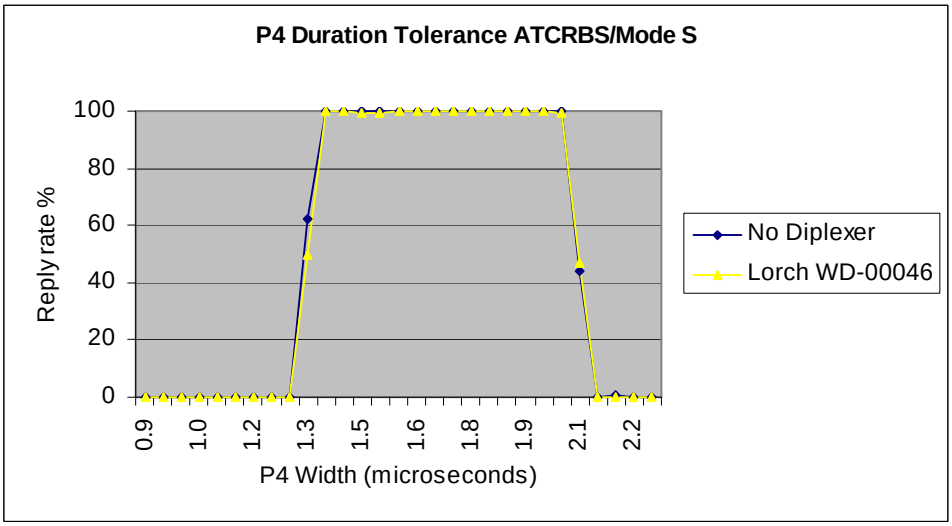

Figure 80 – ATCRBS/Mode S P4 Pulse Duration Tolerance, Transponder MS-2

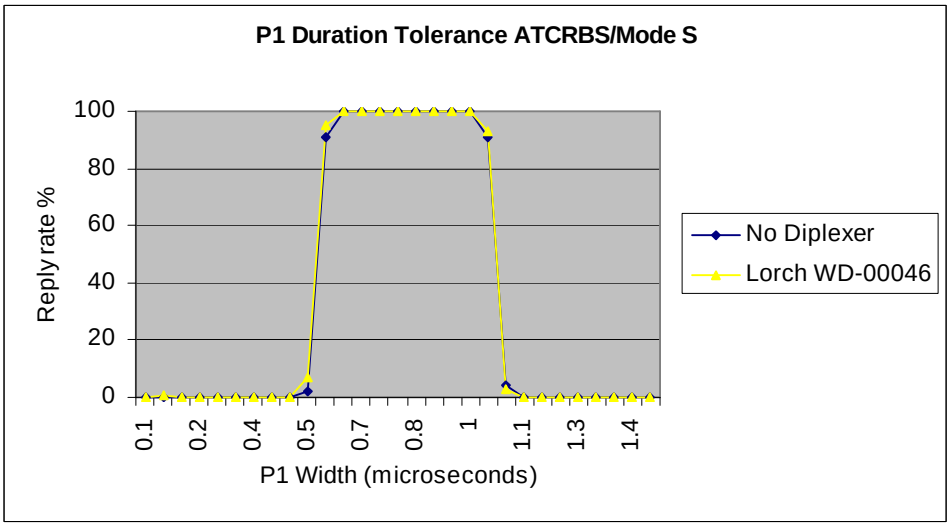

Figure 81 – ATCRBS/Mode S P1 Pulse Duration Tolerance, Transponder MS-3

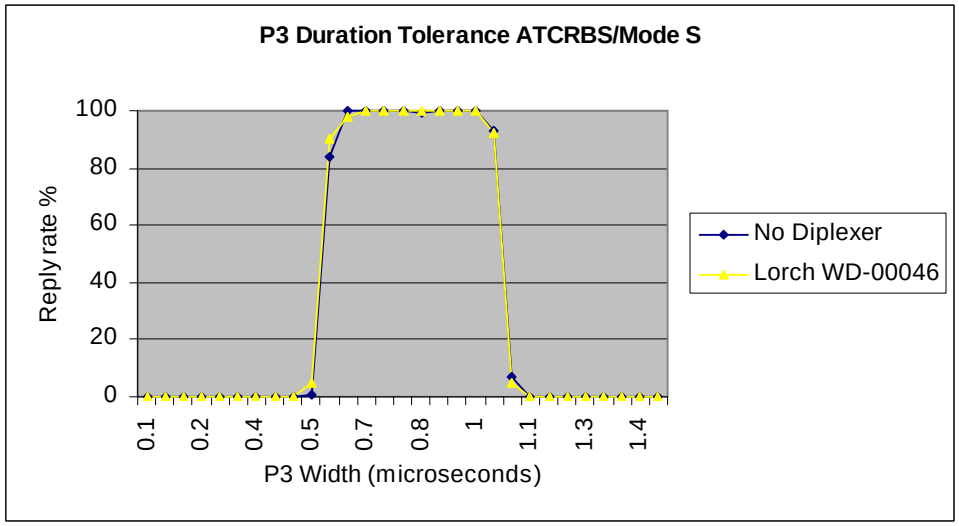

Figure 82 – ATCRBS/Mode S P3 Pulse Duration Tolerance, Transponder MS-3

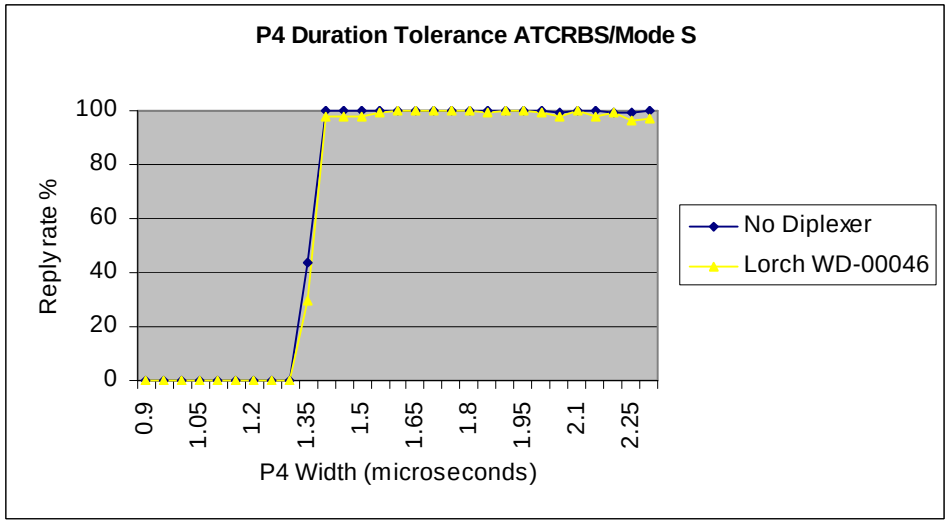

Figure 83 – ATCRBS/Mode S P4 Pulse Duration Tolerance, Transponder MS-3

PULSE LEVEL TOLERANCES, ATCRBS/MODE S ALL-CALL

The transponder is required to accept an interrogation as an ATCRBS/Mode S All-Call as valid if the amplitude of the P4 pulse is greater than the amplitude of P3 minus 1 dB. The transponder is required to accept an interrogation as a valid ATCRBS interrogation if the amplitude of the P4 pulse is less than the amplitude of P3 minus 6 dB. Tests were conducted to measure the P4 level acceptance with each test configuration. Figures 84 through 86 show that there is no significant effect.

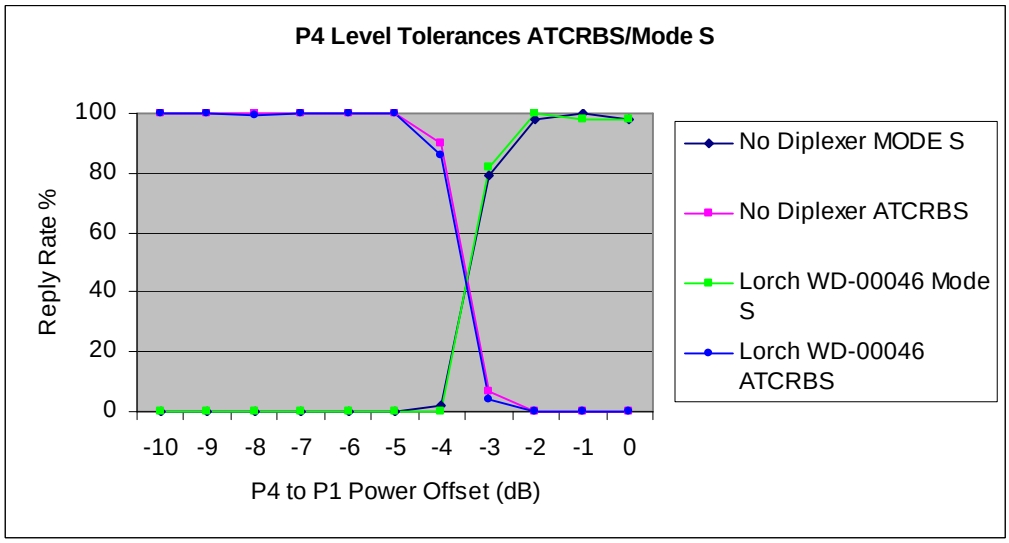

Figure 84 – ATCRBS/Mode S P4 Pulse Level Tolerance, Transponder MS-1

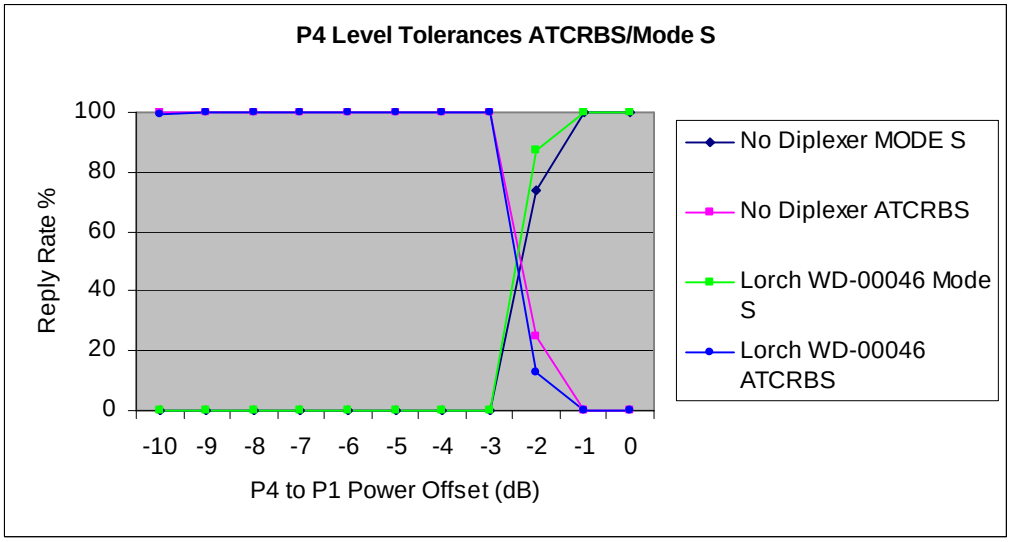

Figure 85 – ATCRBS/Mode S P4 Pulse Level Tolerance, Transponder MS-2

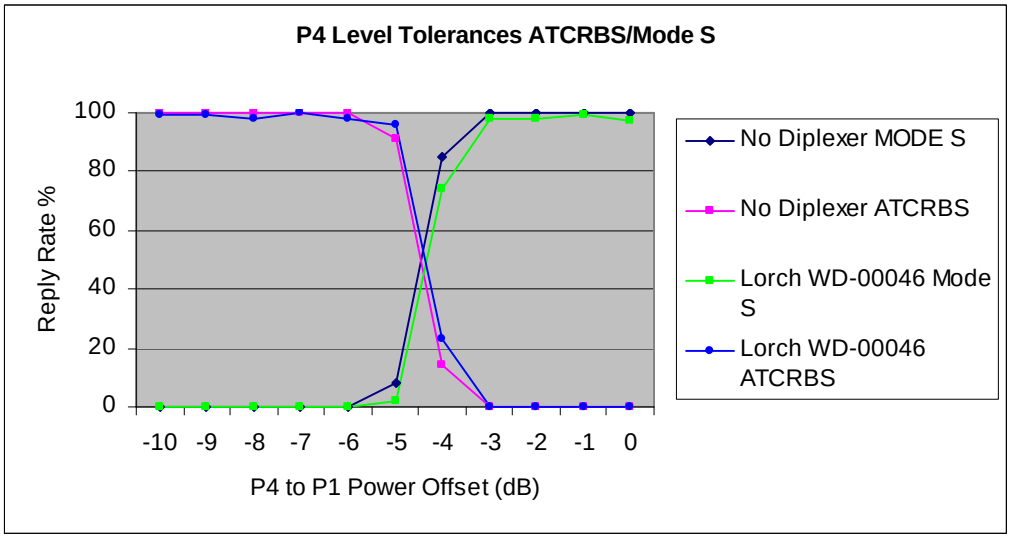

Figure 86 – ATCRBS/Mode S P4 Pulse Level Tolerance, Transponder MS-3

SYNC PHASE REVERSAL POSITION TOLERANCE

Mode S transponders are required to accept interrogations as valid if the sync phase reversal is received within the interval from 1.2 to 1.3 microseconds following the leading edge of P6. The interrogation is to be rejected if the sync phase is received outside the interval from 1.05 to 1.45 microseconds after the leading edge of P6. Tests were conducted to measure the sync phase reversal position tolerance with each of the test configurations. Figures 87 through 89 show that the Diplexers had no effect.

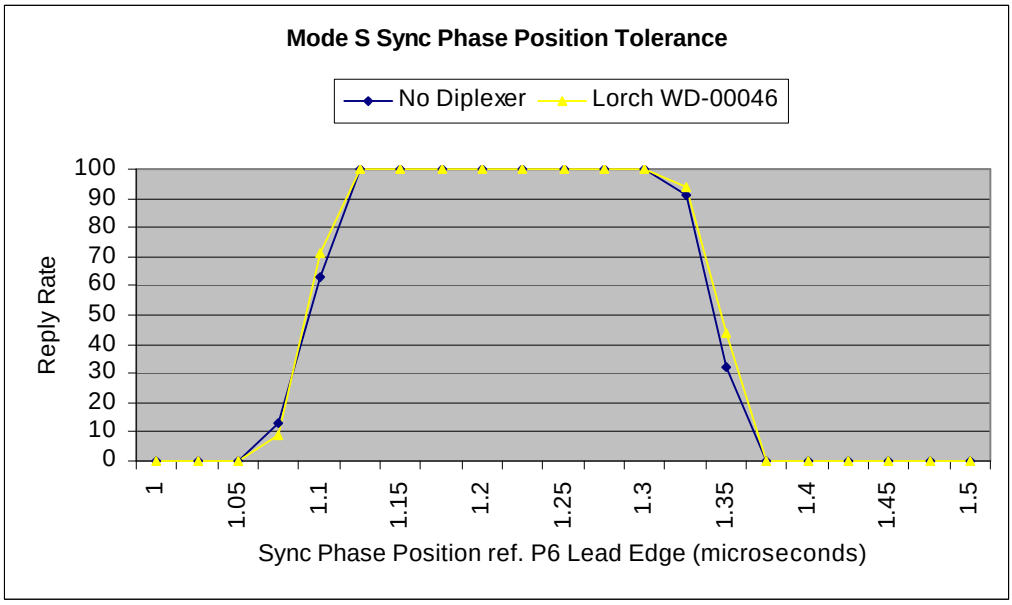

Figure 87 – Mode S Sync Phase Position Tolerance, Transponder MS-1

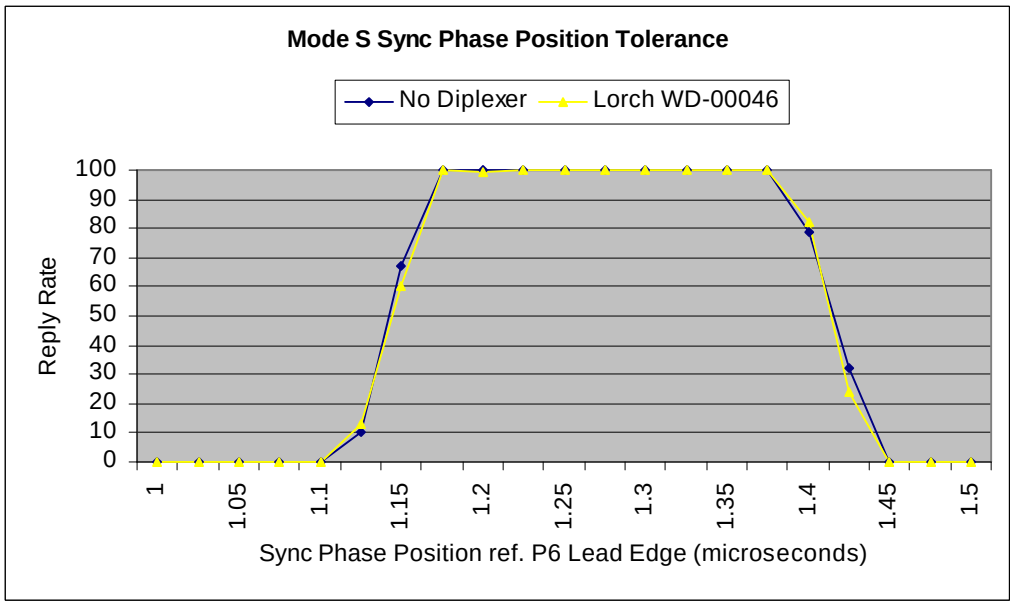

Figure 88 – Mode S Sync Phase Position Tolerance, Transponder MS-2

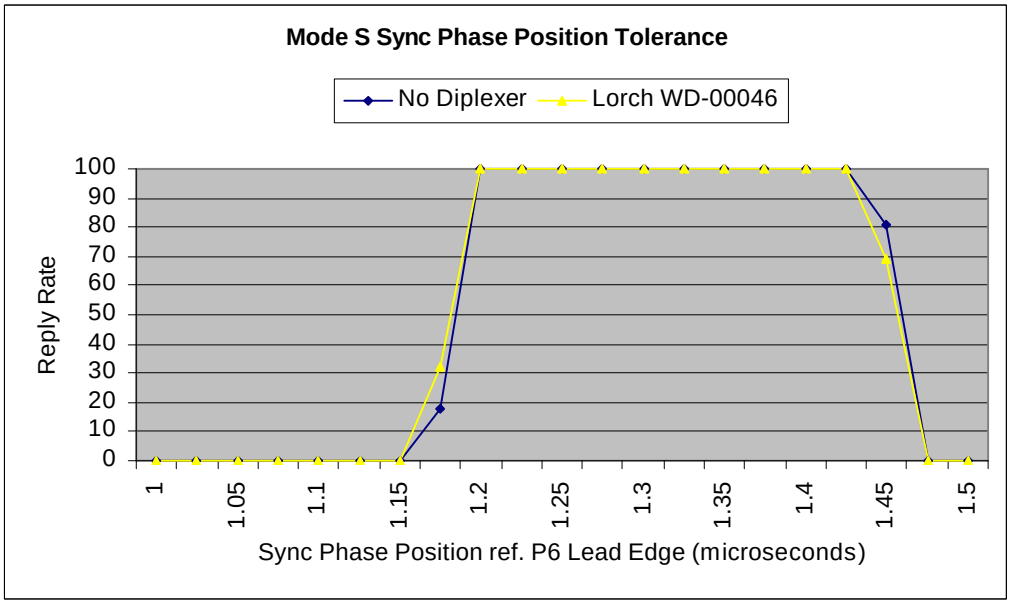

Figure 89 – Mode S Sync Phase Position Tolerance, Transponder MS-3

SIDE LOBE SUPPRESSION (SLS) DECODING

The transponder is required to suppress when a valid suppression pulse of equal or greater amplitude to P1 is received in the interval between 1.85 to 2.15 microseconds from P1. The transponder is required to reply to at least 90 percent of interrogations when no suppression pulse is received within the interval from 1.3 to 2.7 microseconds. SLS decoding tests were conducted on the transponders in each configuration to determine if the Diplexer had an effect on SLS characteristics. Figures 90 through 96 show that there was no effect on SLS decoding.

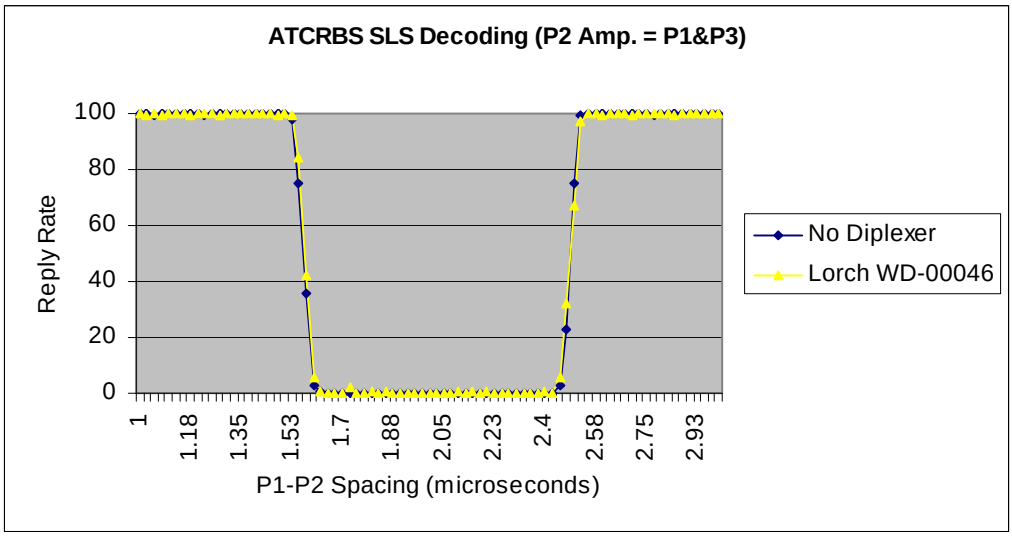

Figure 90 – SLS Decoding, Transponder MS-1

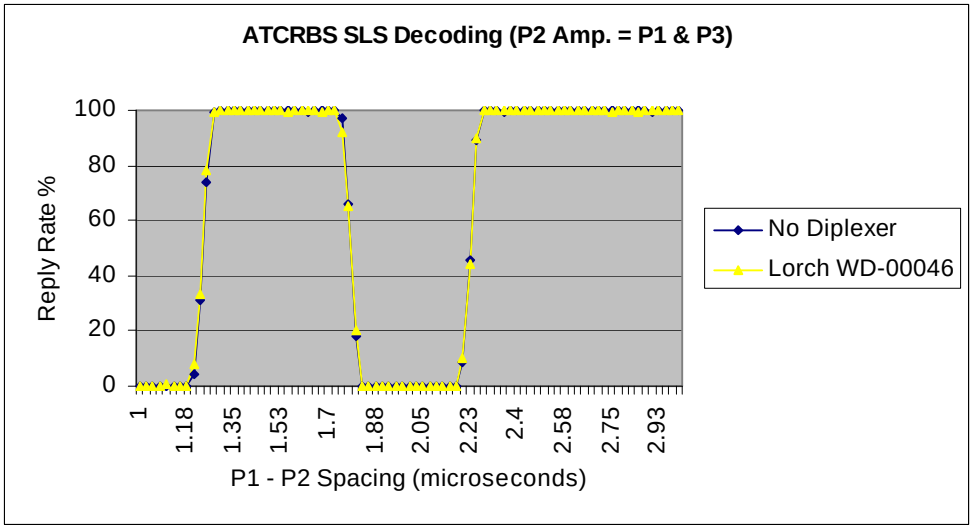

Figure 91 – SLS Decoding, Transponder MS-2

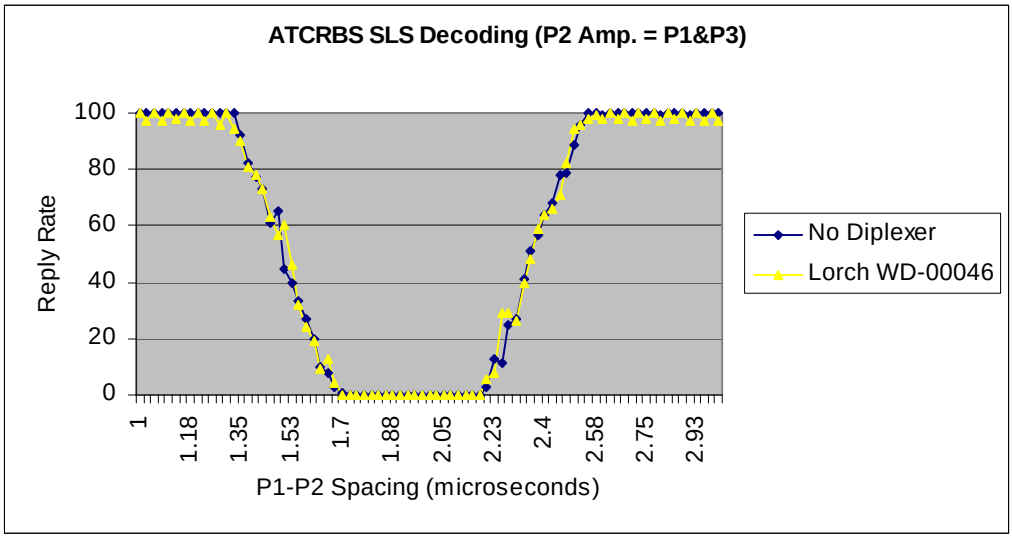

Figure 92 – SLS Decoding, Transponder MS-3

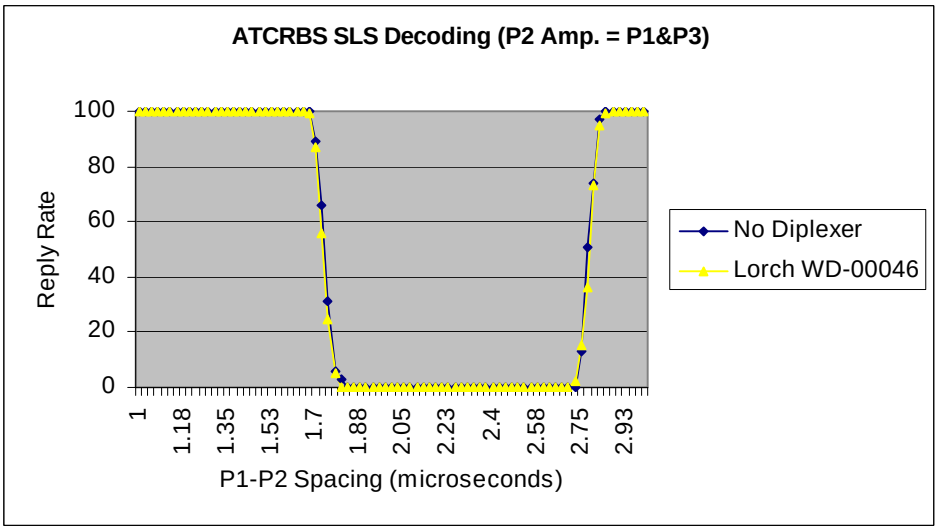

Figure 93 – SLS Decoding, Transponder A-1

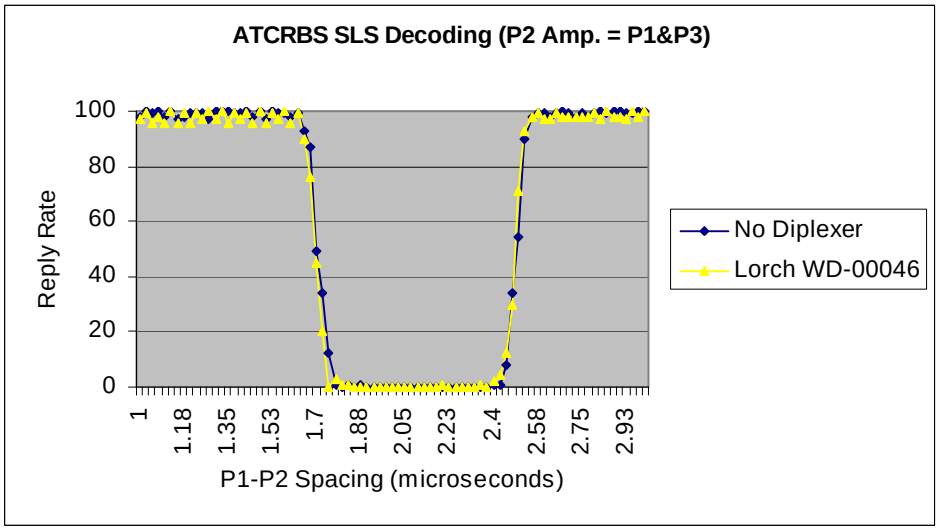

Figure 94 – SLS Decoding, Transponder A-2

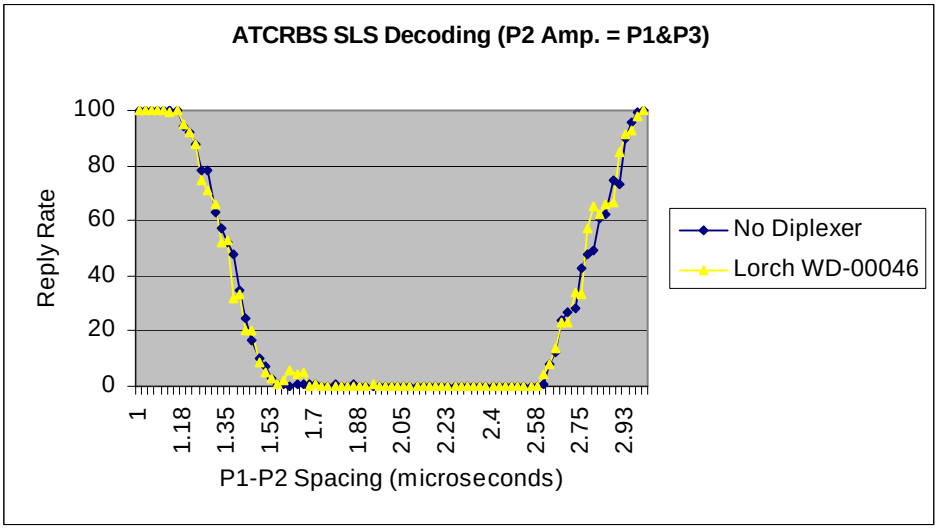

Figure 95 – SLS Decoding, Transponder A-3

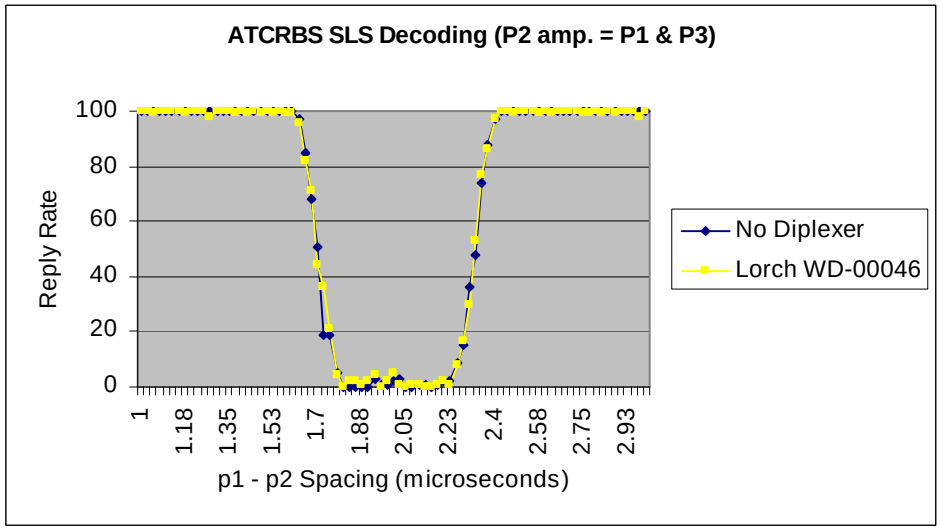

Figure 96 – SLS Decoding, Transponder A-4

SLS DECODING ATCRBS/MODE S

The SLS decoding tests were repeated with a P4 pulse present to measure the ATCRBS/Mode S SLS decoding characteristics. Figures 97 through 99 show the Mode S reply rate with no effect from the Diplexers.

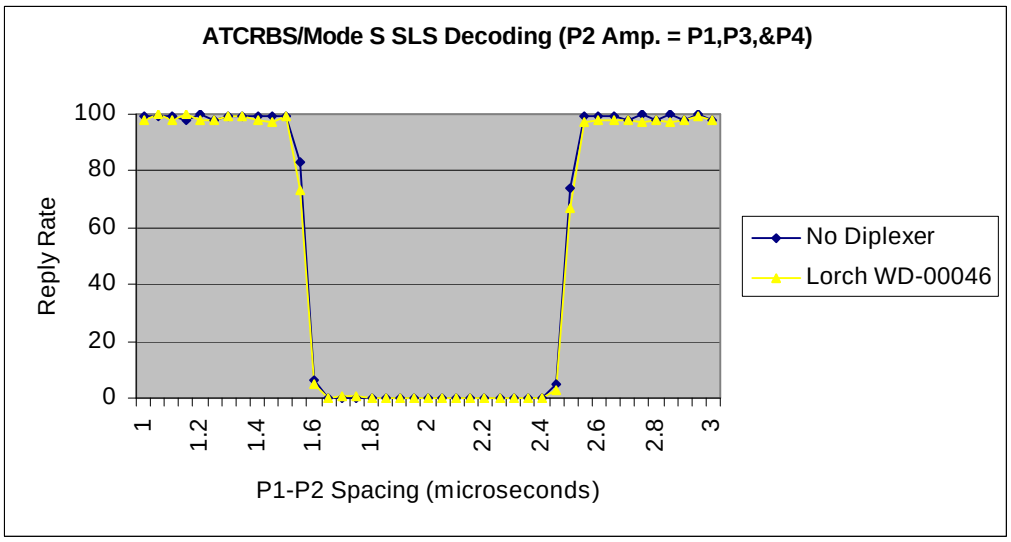

Figure 97 – SLS Decoding, ATCRBS/Mode S Transponder MS-1

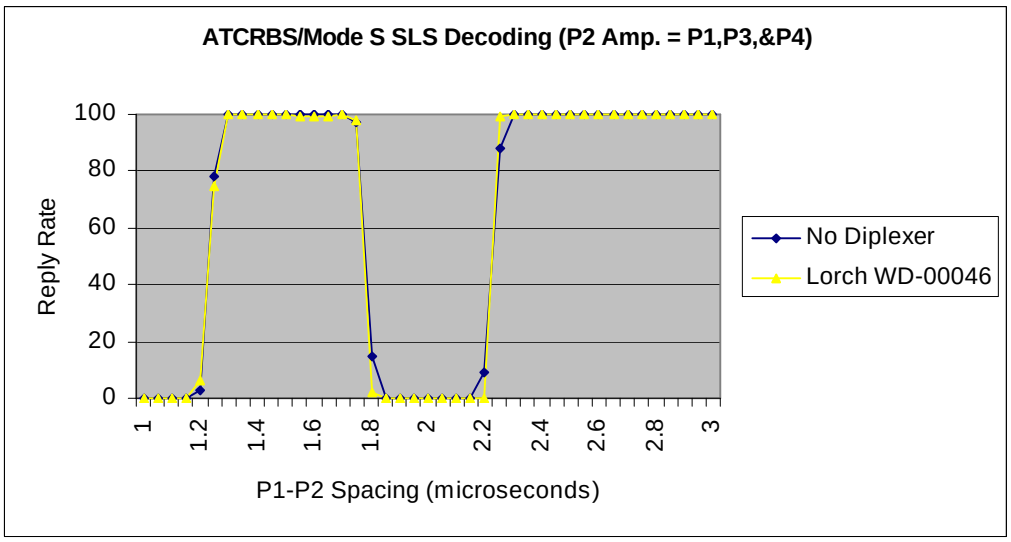

Figure 98 – SLS Decoding, ATCRBS/Mode S Transponder MS-2

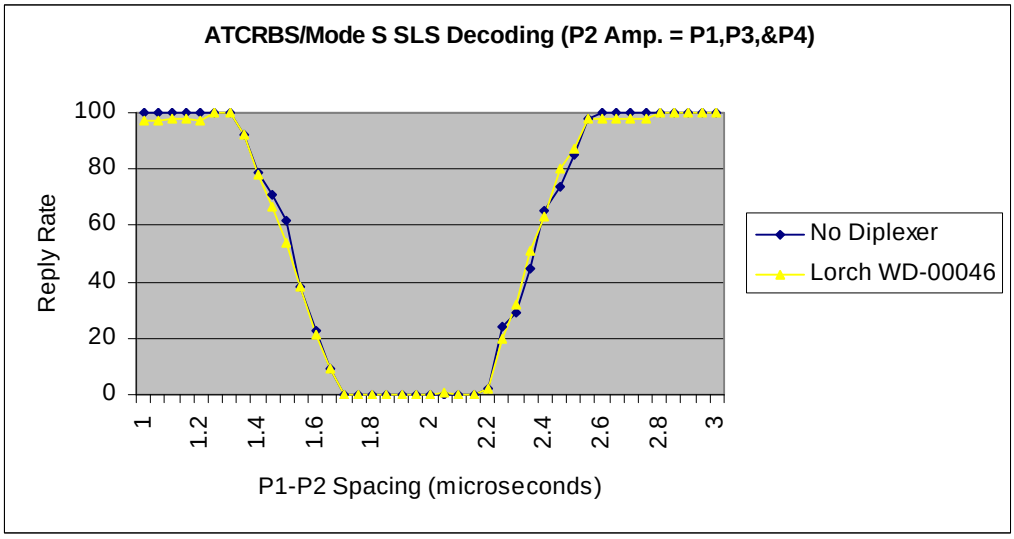

Figure 99 – SLS Decoding, ATCRBS/Mode S Transponder MS-3

SLS PULSE RATIO

The transponder shall not be suppressed if the level of P1 exceeds the level of P2 by 9 dB or more. Tests were conducted with the suppression pulse 9 dB below that of P1 to determine if the Diplexer had an effect on SLS pulse ratio. Figures 100 through 106 show that there is no effect.

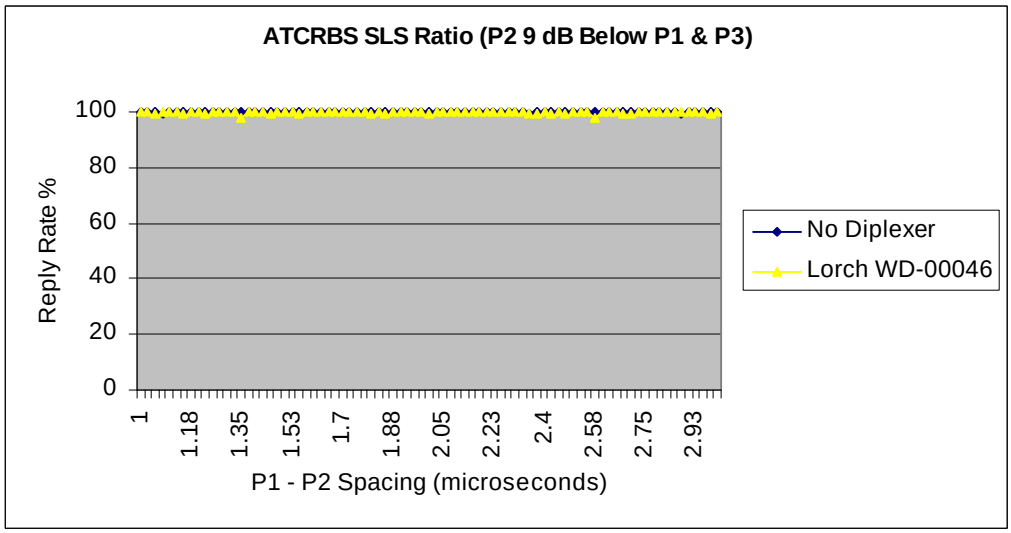

Figure 100 – SLS Ratio, ATCRBS, Transponder MS-1

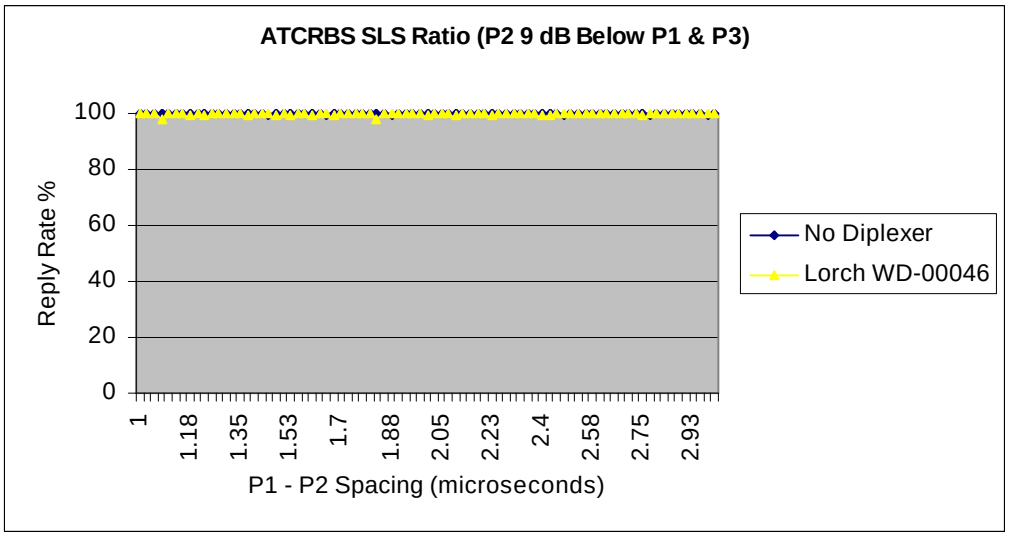

Figure 101 – SLS Ratio, ATCRBS, Transponder MS-2

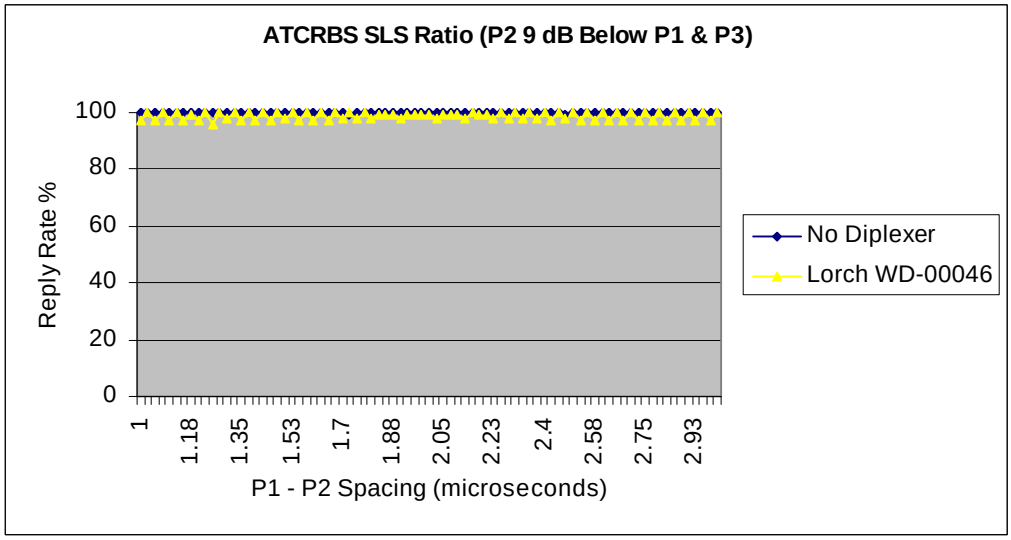

Figure 102 – SLS Ratio, ATCRBS, Transponder MS-3

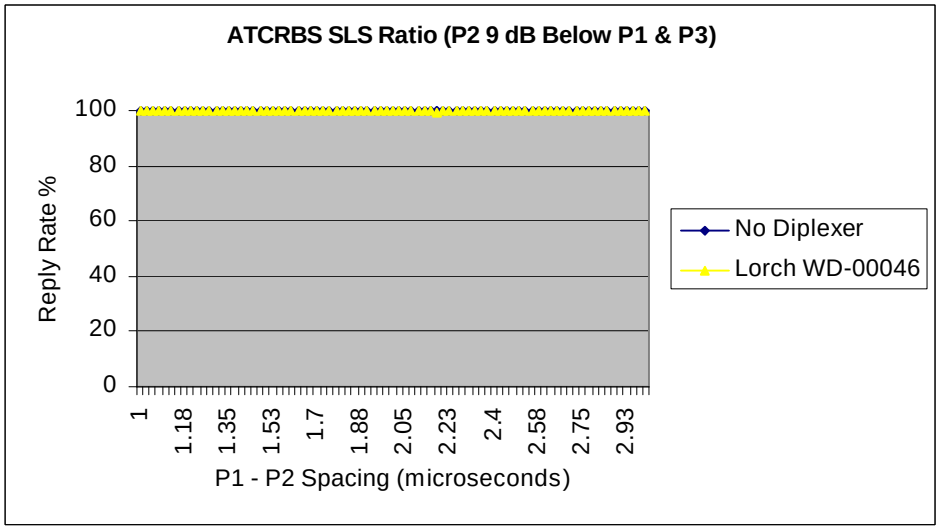

Figure 103 – SLS Ratio, ATCRBS, Transponder A-1

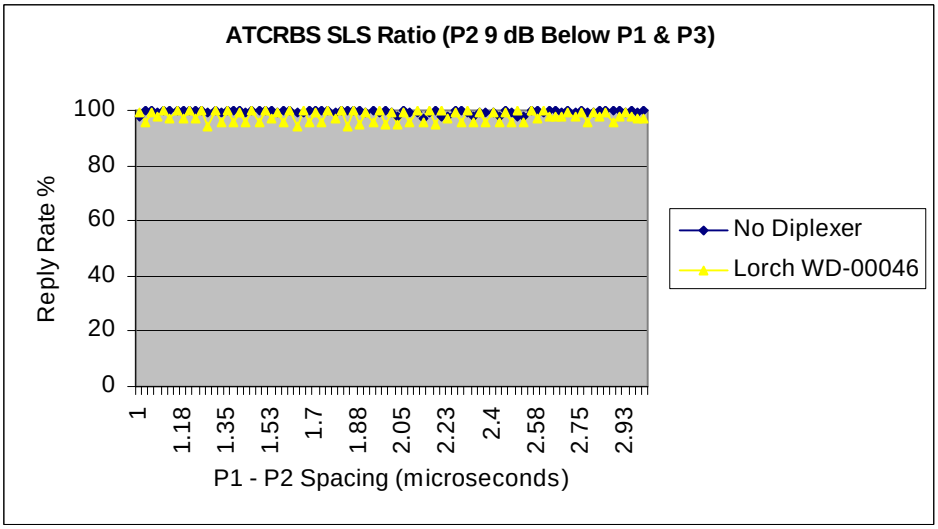

Figure 104 – SLS Ratio, ATCRBS, Transponder A-2

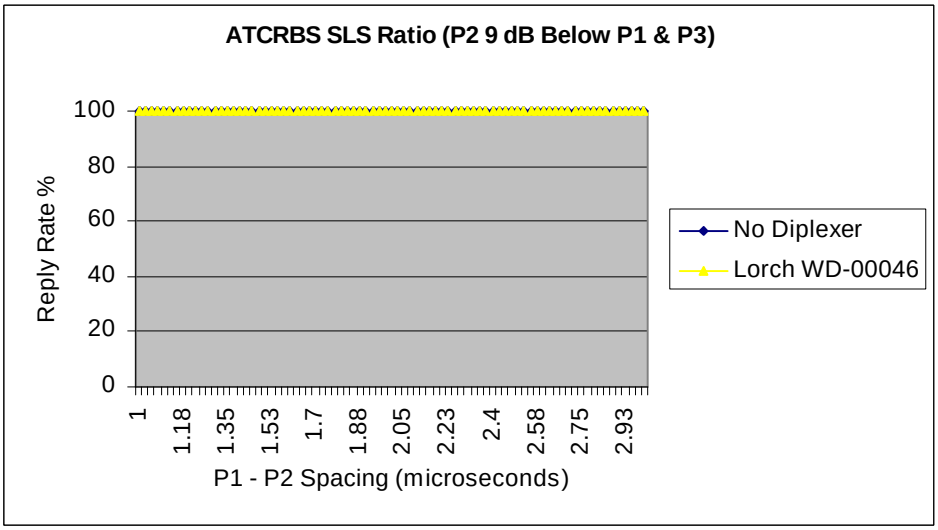

Figure 105 – SLS Ratio, ATCRBS, Transponder A-3

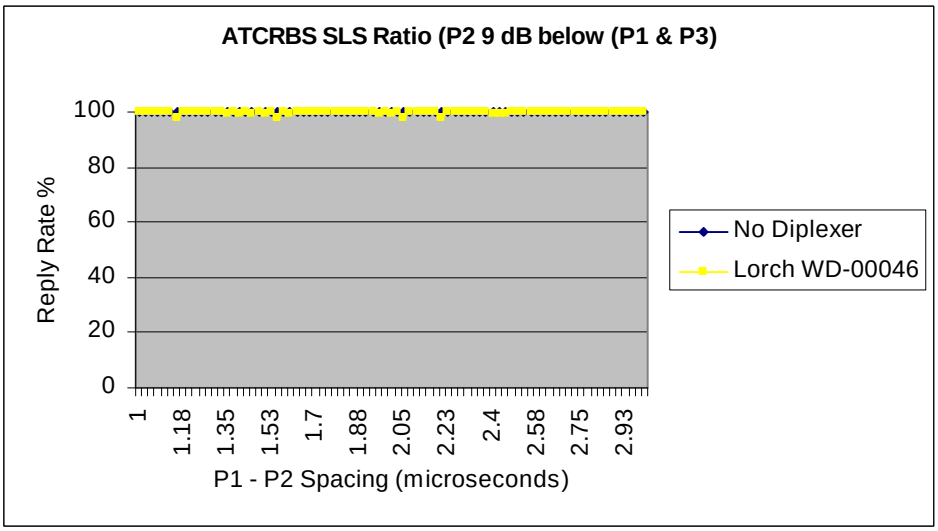

Figure 106 – SLS Ratio, ATCRBS, Transponder A-4

SLS RATIO ATCRBS/MODE S

The SLS ratio tests were repeated with a P4 pulse present to measure the ATCRBS/Mode S SLS ratio characteristics. Figures 107 through 109 show the Mode S reply rate with no effect from the Diplexer.

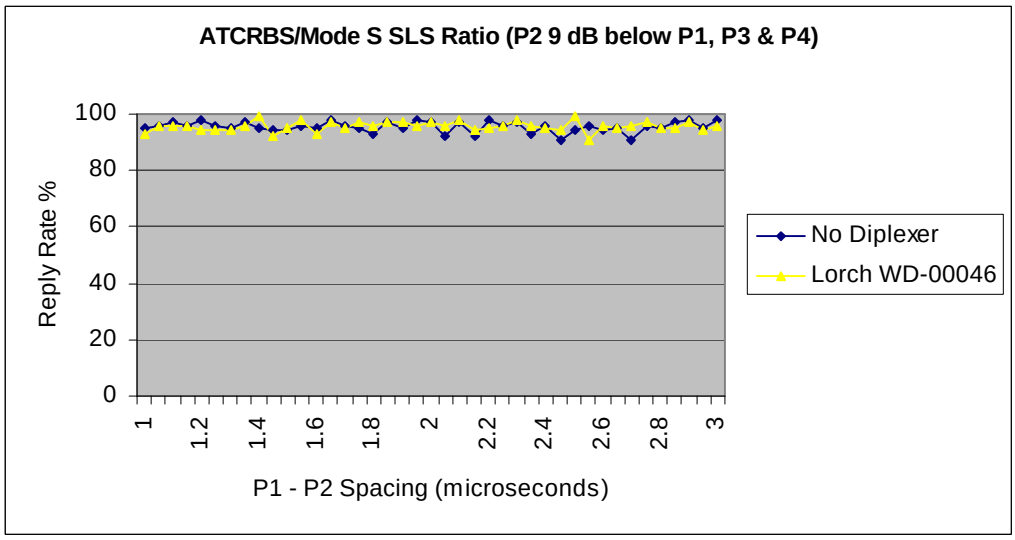

Figure 107 – SLS Ratio, ATCRBS/Mode S, Transponder MS-1

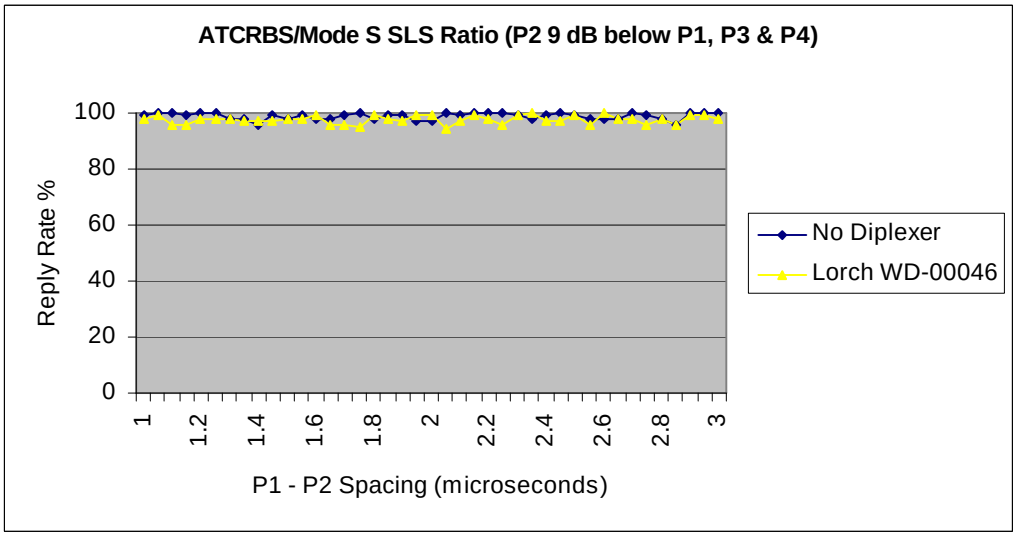

Figure 108 – SLS Ratio, ATCRBS/Mode S, Transponder MS-2

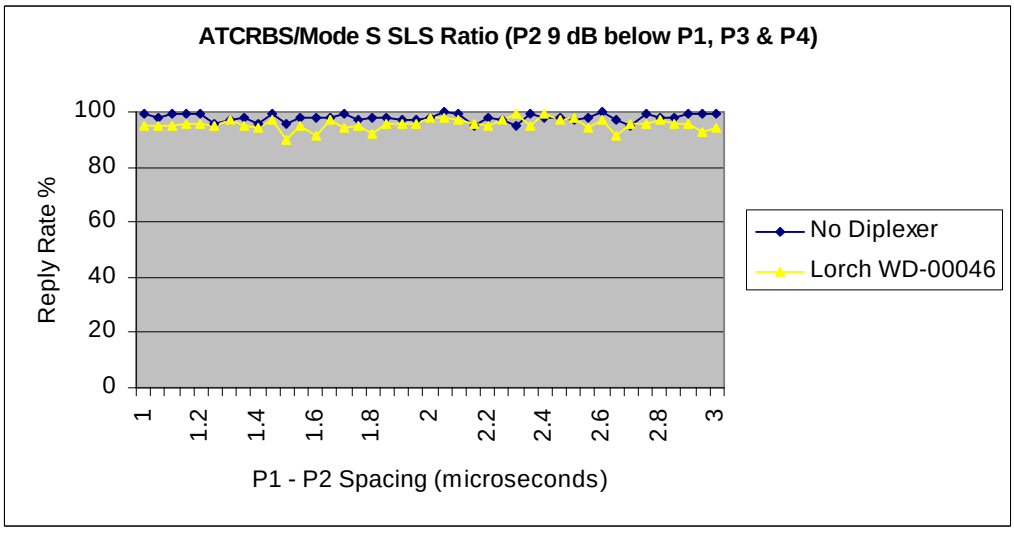

Figure 109 – SLS Ratio, ATCRBS/Mode S, Transponder MS-3

SUPPRESSION DURATION

The suppression duration is the time interval between the leading edges of a P2 pulse of a suppression pair and the P1 pulse of the earliest subsequent interrogation to which the transponder replies. The suppression duration is required to be between 25 and 45 microseconds. The suppression duration was measured for each transponder with the various Diplexer configurations. Both Mode A and Mode C suppression duration was measured and in all cases the Mode A and Mode C suppression duration was virtually identical. For this reason, only the Mode A suppression duration plots are presented here. Figures 110 through 116 show that there was no effect from the Diplexer in suppression duration.

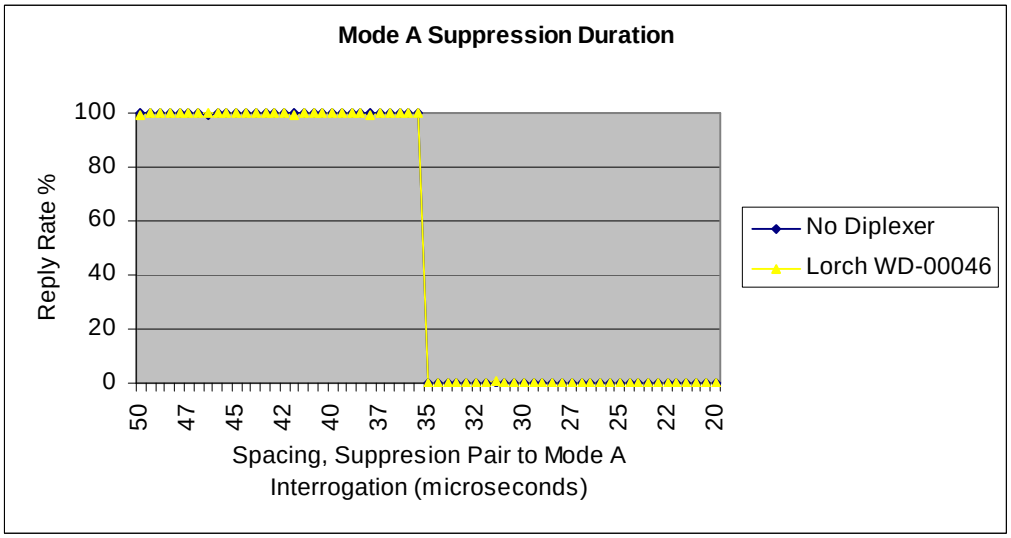

Figure 110 – Mode A Suppression Duration, Transponder MS-1

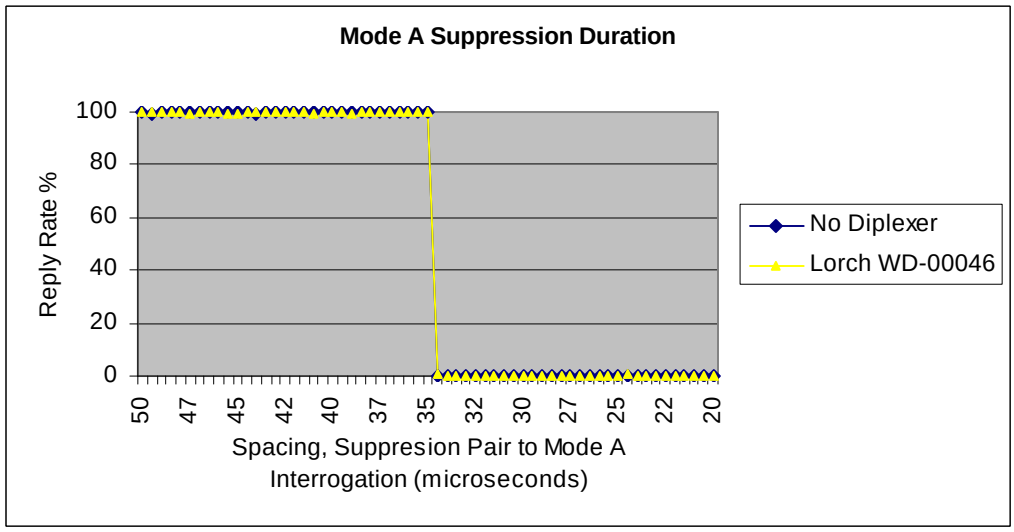

Figure 111 – Mode A Suppression Duration, Transponder MS-2

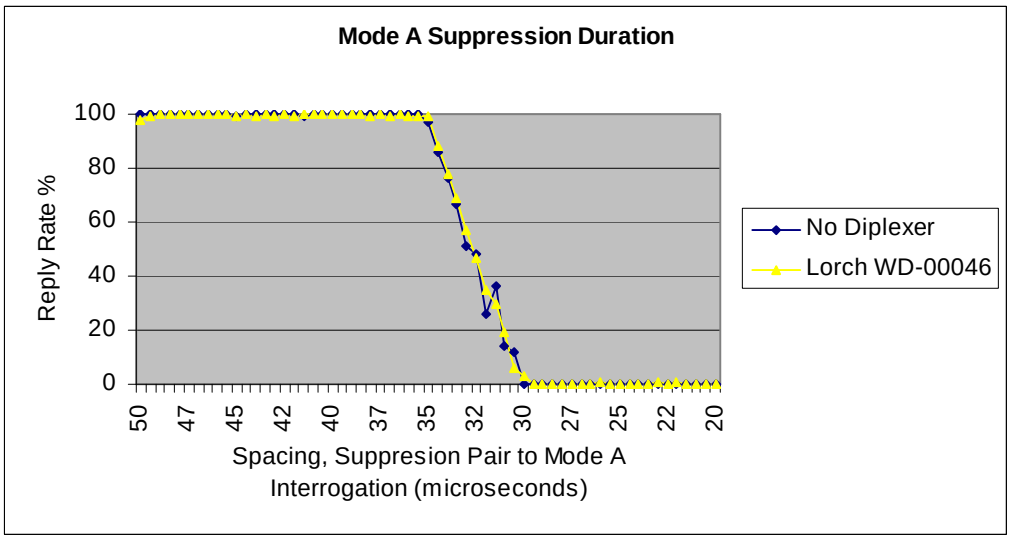

Figure 112 – Mode A Suppression Duration, Transponder MS-3

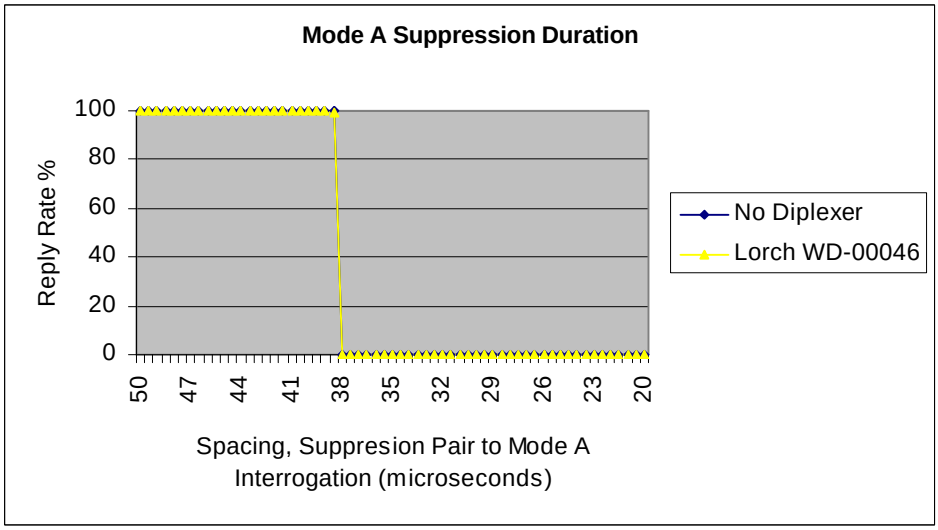

Figure 113 – Mode A Suppression Duration, Transponder A-1

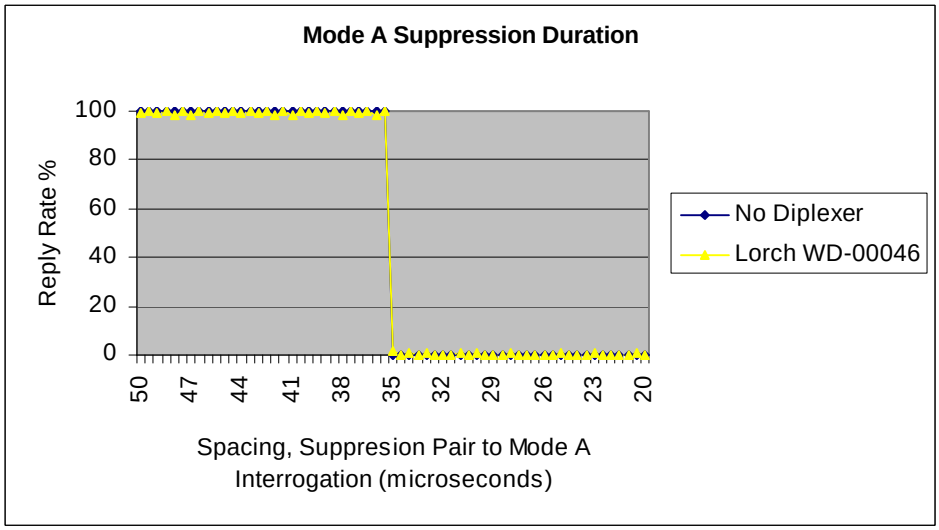

Figure 114 – Mode A Suppression Duration, Transponder A-2

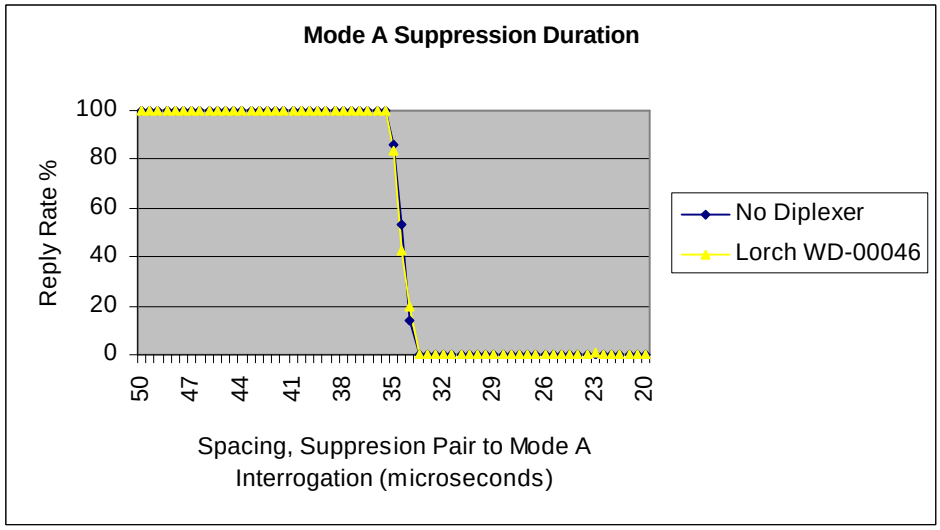

Figure 115 – Mode A Suppression Duration, Transponder A-3

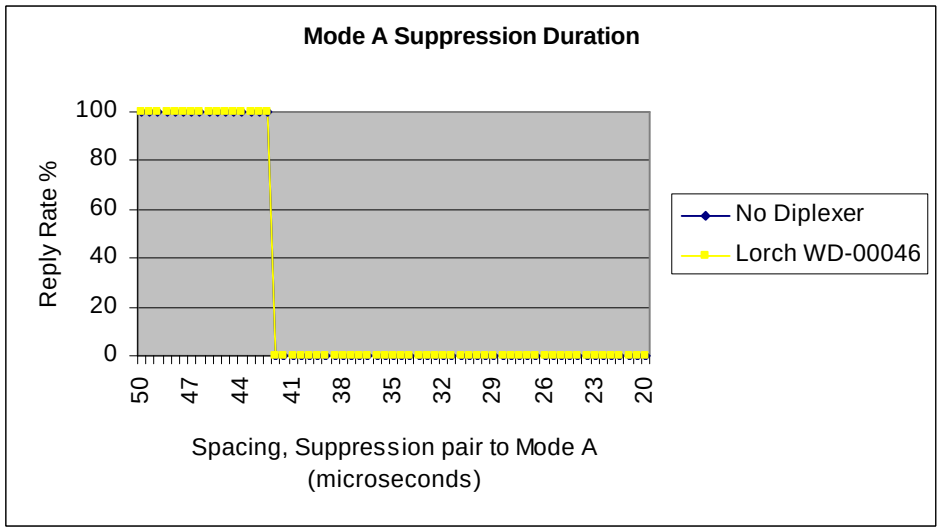

Figure 116 – Mode A Suppression Duration, Transponder A-4

SUPPRESSION REINITIATION

The transponder is required to have the capability to reinitiate suppression within two microseconds of the end of a suppression period. Suppression reinitiation was tested by measuring suppression duration initiated by a suppression pair positioned two microseconds after the end of a suppression period. Figures 117 through 123 show that the Diplexer had no effect on suppression reinitiation.

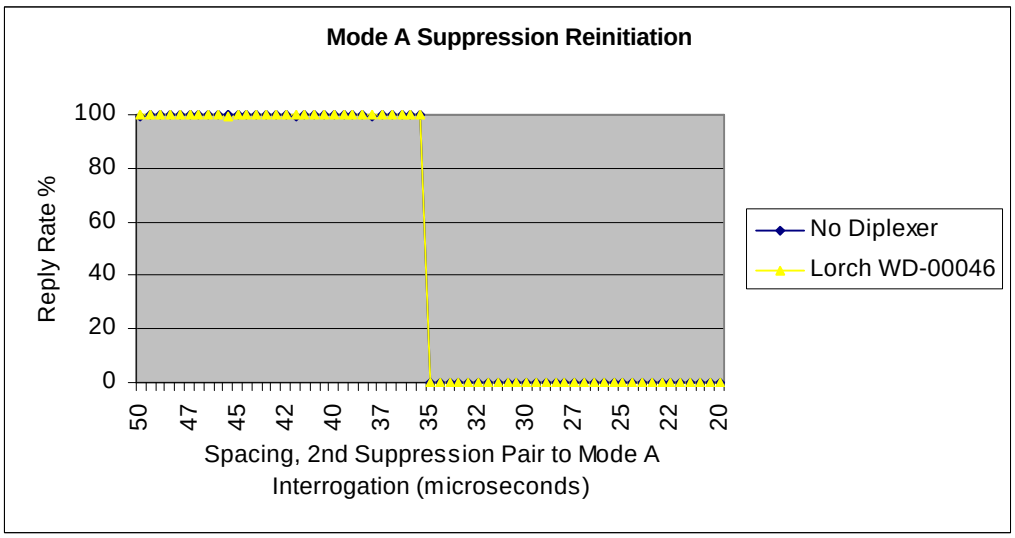

Figure 117 – Mode A Suppression Reinitiation, Transponder MS-1

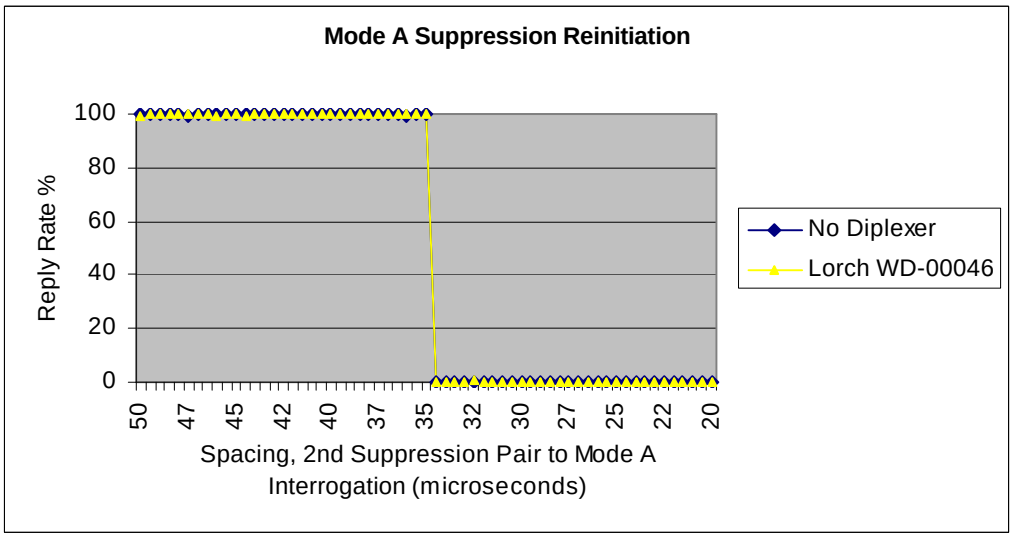

Figure 118 – Mode A Suppression Reinitiation, Transponder MS-2

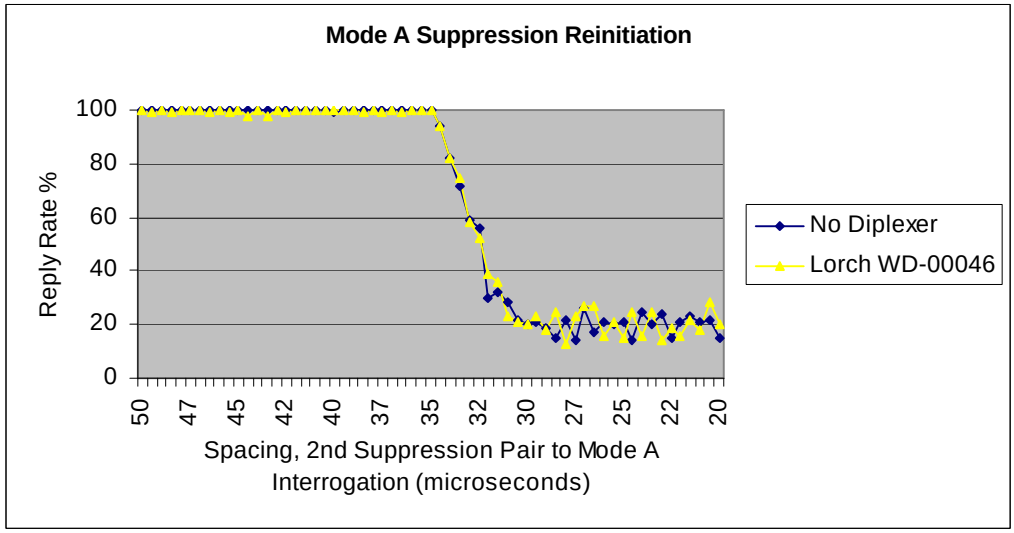

Figure 119 – Mode A Suppression Reinitiation, Transponder MS-3

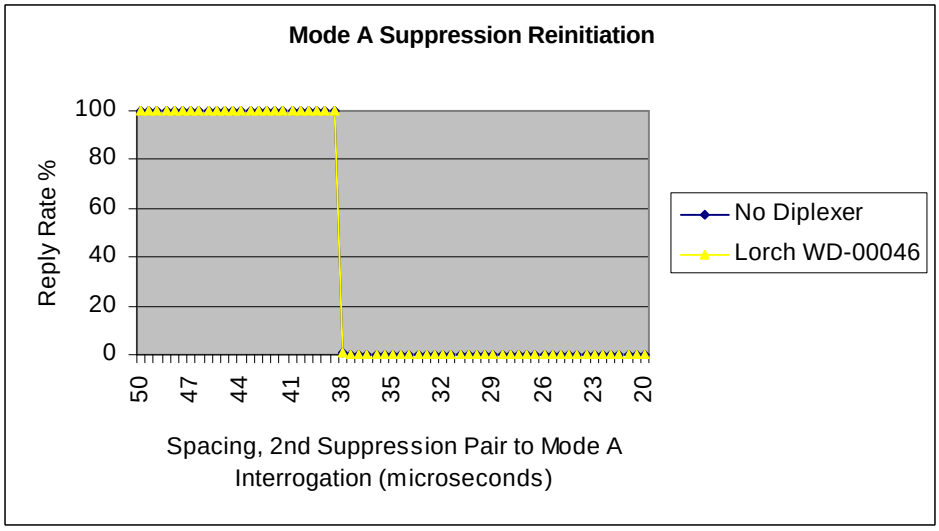

Figure 120 – Mode A Suppression Reinitiation, Transponder A-1

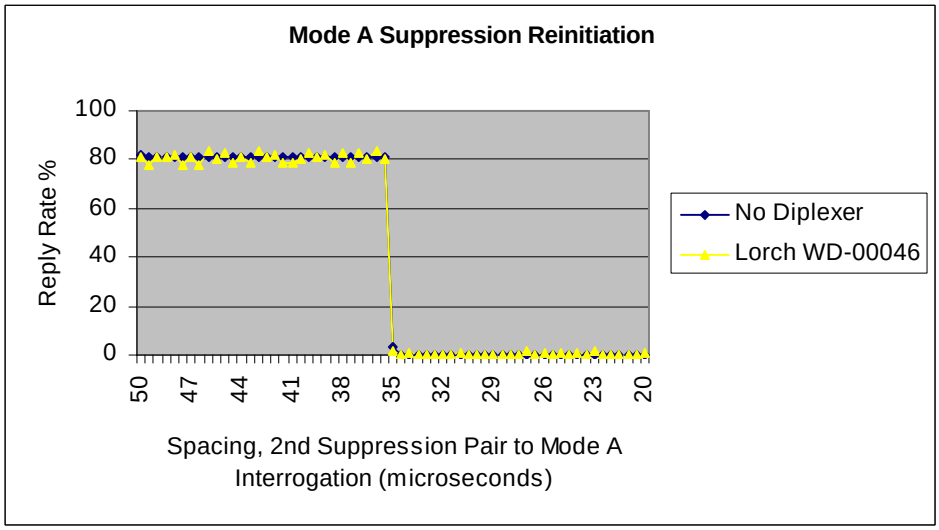

Figure 121 – Mode A Suppression Reinitiation, Transponder A-2

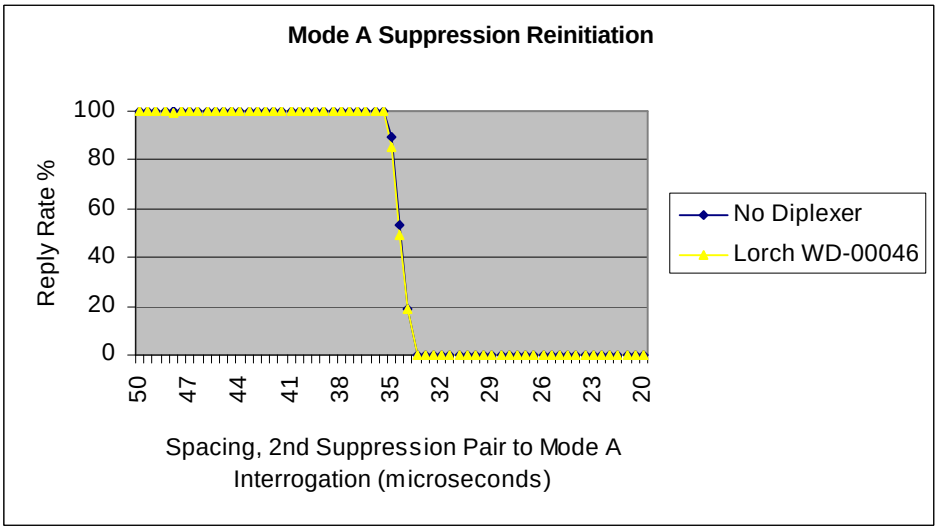

Figure 122 – Mode A Suppression Reinitiation, Transponder A-3

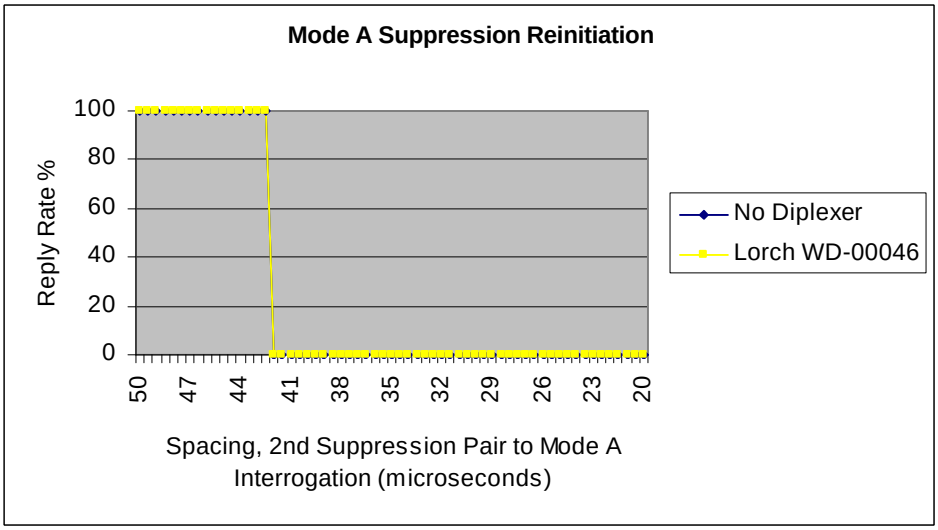

Figure 123 – Mode A Suppression Reinitiation, Transponder A-4

RECOVERY FROM SUPPRESSION

The transponder receiver sensitivity is required to be at MTL no later than one microsecond after the end of the suppression period. Suppression recovery was measured by measuring suppression duration with the Mode A interrogation following the suppression pair at MTL. Figures 124 through 130 show that there was no effect from the Diplexer on suppression recovery.

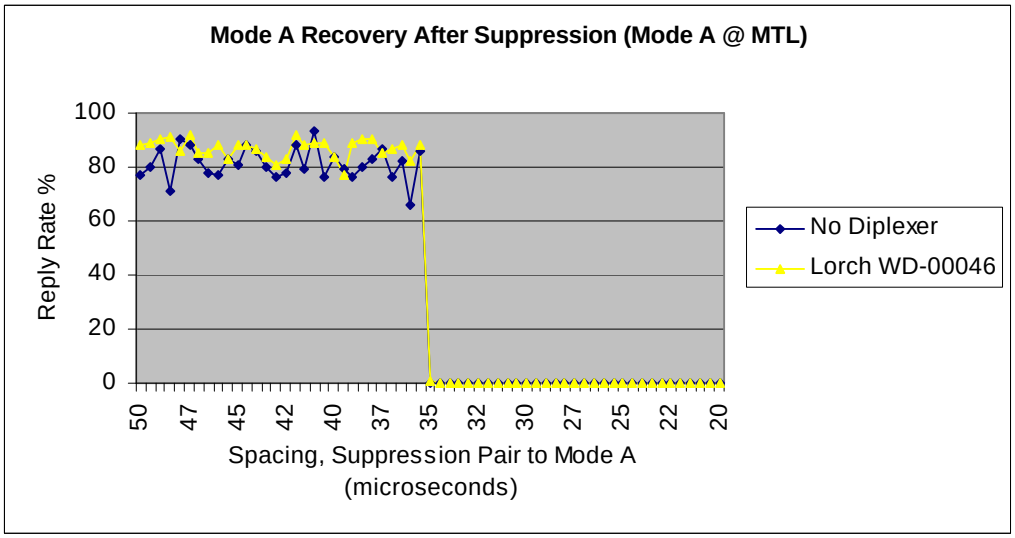

Figure 124 – Recovery After Suppression, Transponder MS-1

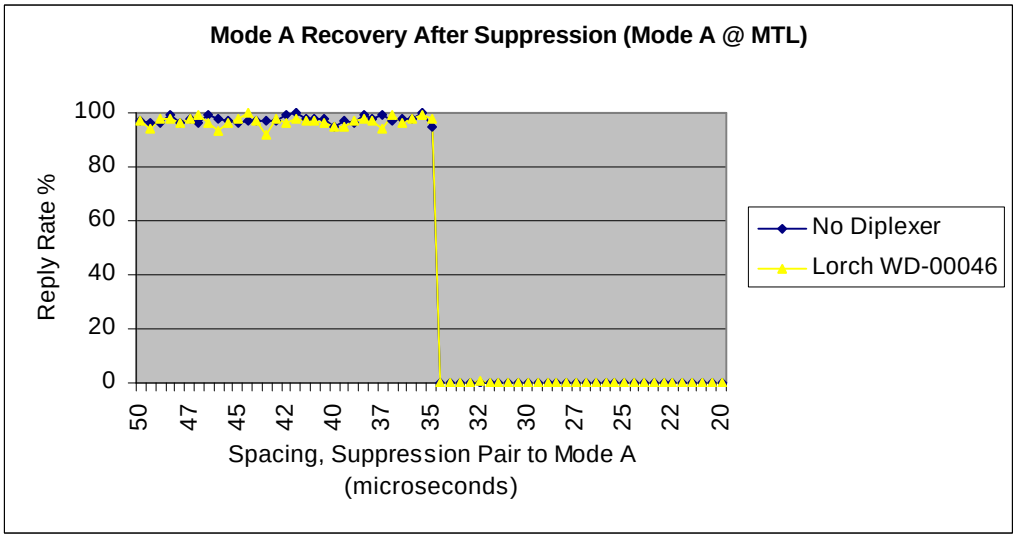

Figure 125 – Recovery After Suppression, Transponder MS-2

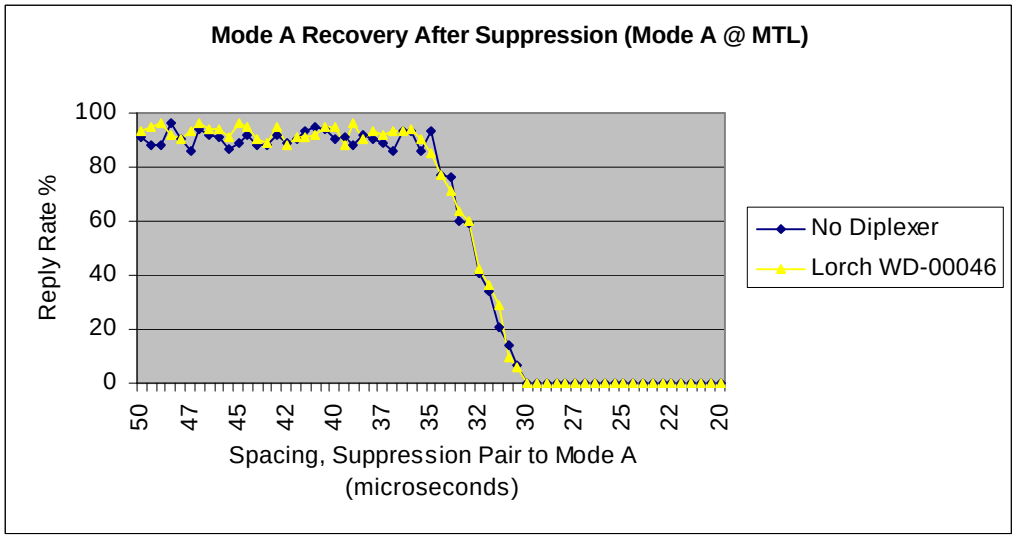

Figure 126 – Recovery After Suppression, Transponder MS-3

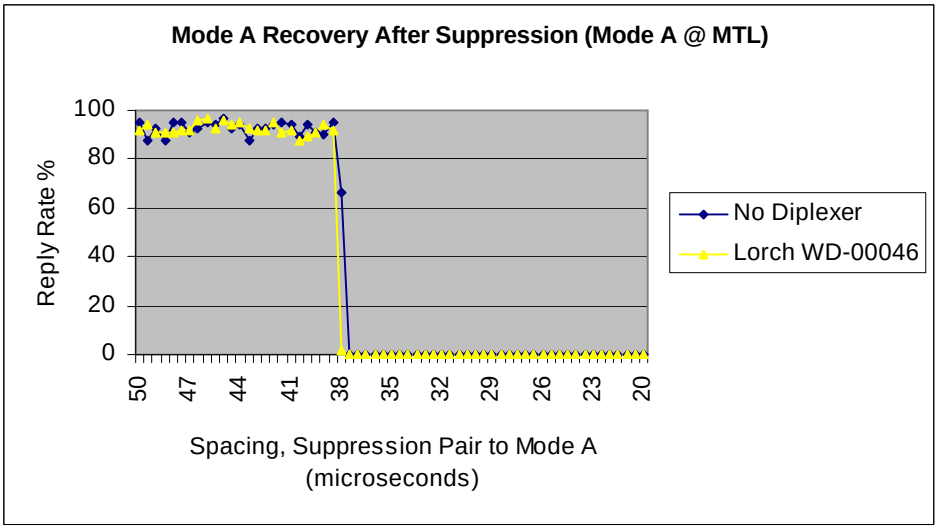

Figure 127 – Recovery After Suppression, Transponder A-1

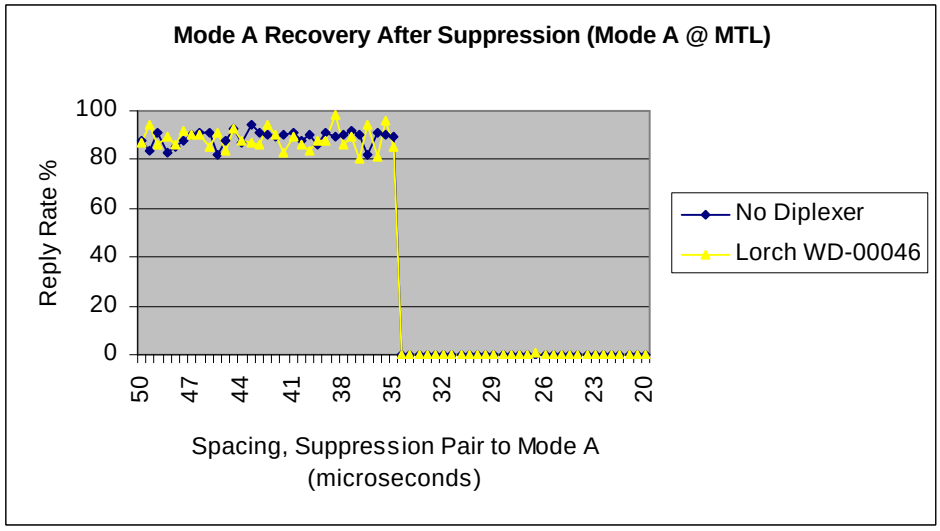

Figure 128 – Recovery After Suppression, Transponder A-2

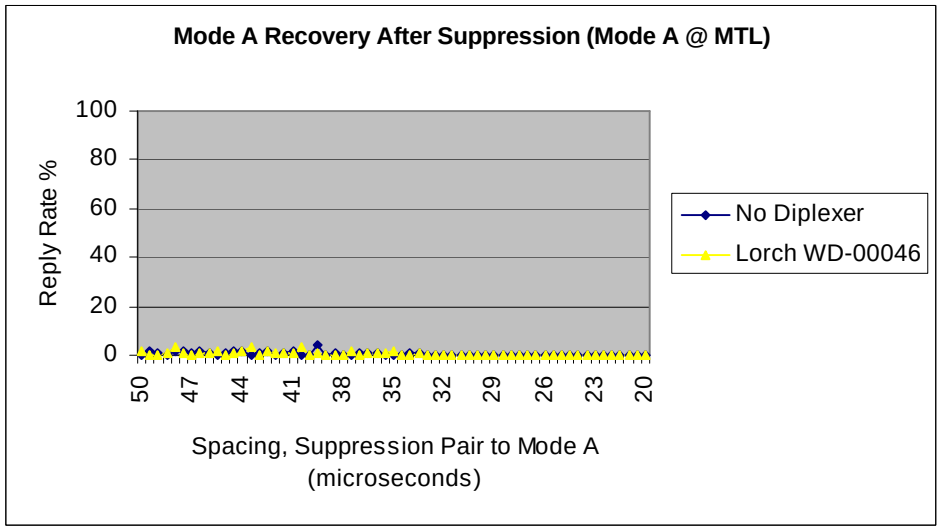

Figure 129 – Recovery After Suppression, Transponder A-3

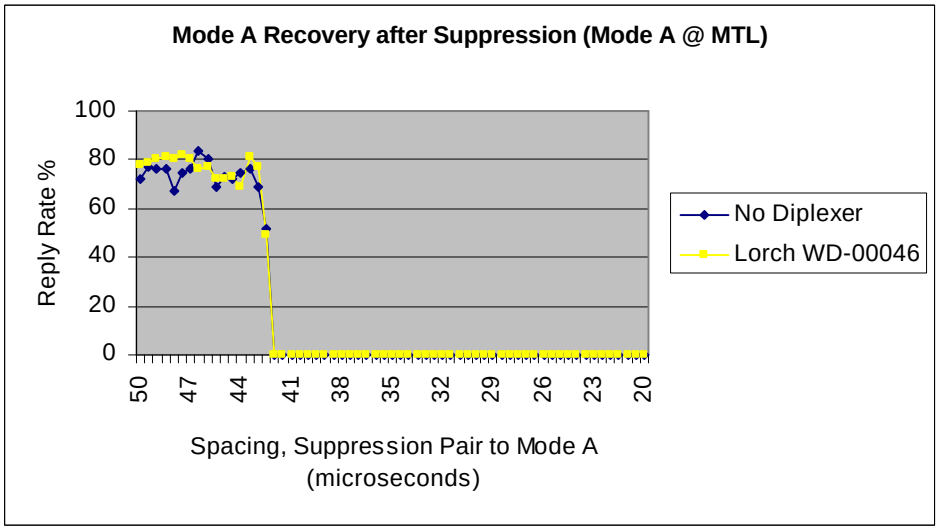

Figure 130 – Recovery After Suppression, Transponder A-4

MODE S SLS

The transponder is required to suppress replies to Mode S format interrogations when a P5 pulse, overlaying the sync phase reversal of P6 exceeds the amplitude of P6 by 3 dB or more. The reply ratio is required to beat least 99 percent if the amplitude of P6 exceeds that of P5 by 12 dB or more. Mode S SLS was tested for the 5 Mode S type transponders. Figures 131 through 133 show that the Diplexer had no effect on Mode S SLS.

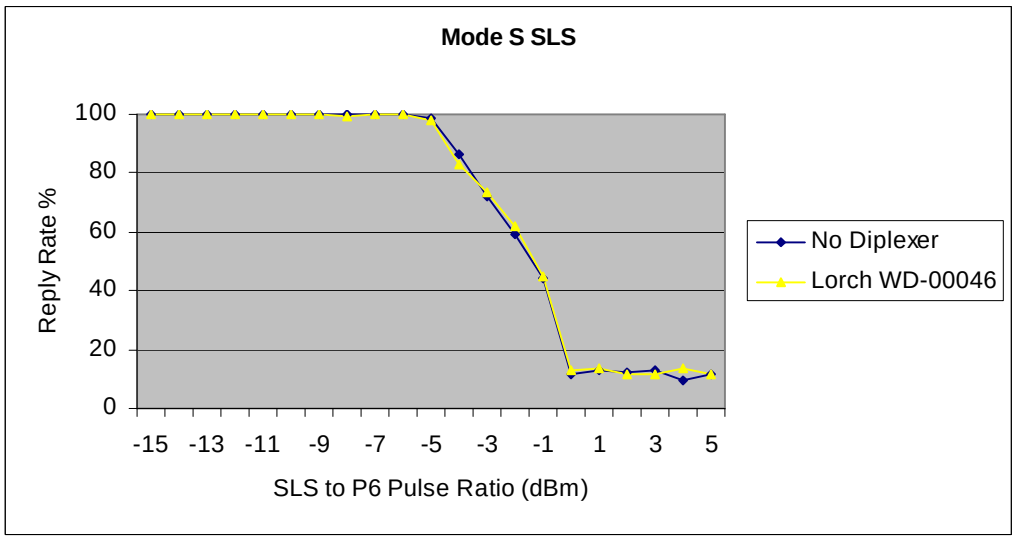

Figure 131 – Mode S Side Lobe Suppression, Transponder MS-1

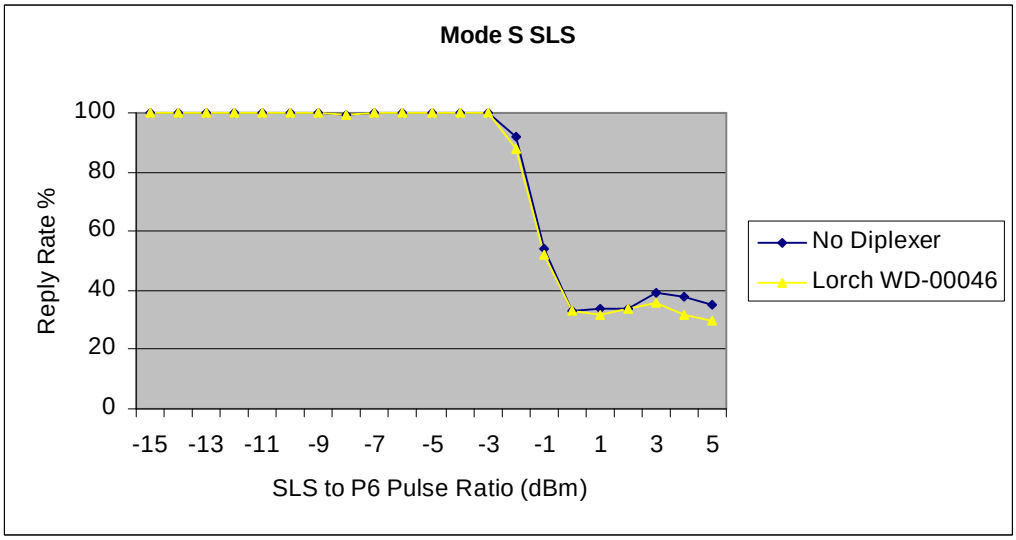

Figure 132 – Mode S Side Lobe Suppression, Transponder MS-2

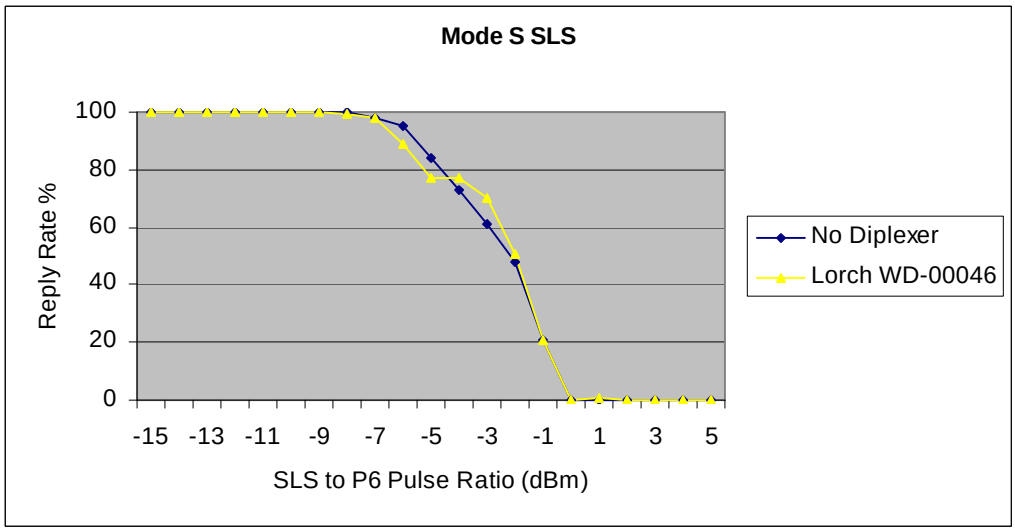

Figure 133 – Mode S Side Lobe Suppression, Transponder MS-3

ATCRBS DESENSITIZATION PULSE AND RECOVERY

When a transponder receives a pulse of more than 0.7 microseconds in duration, it is required to be desensitized temporarily by raising the receiver threshold. Immediately after the desensitizing pulse, the sensitivity is reduced to somewhere between the level of the desensitizing pulse and 9 dB below that. Tests were conducted to measure the recovery from a desensitization pulse for each transponder configuration. Figures 134 through 140 show that there was no effect from the Diplexer. Note: When the desensitizing pulse combines with P1, for either a valid Mode A or Mode C interrogation, the transponder replies to this without being desensitized. This is indicated by the spikes in the curves.

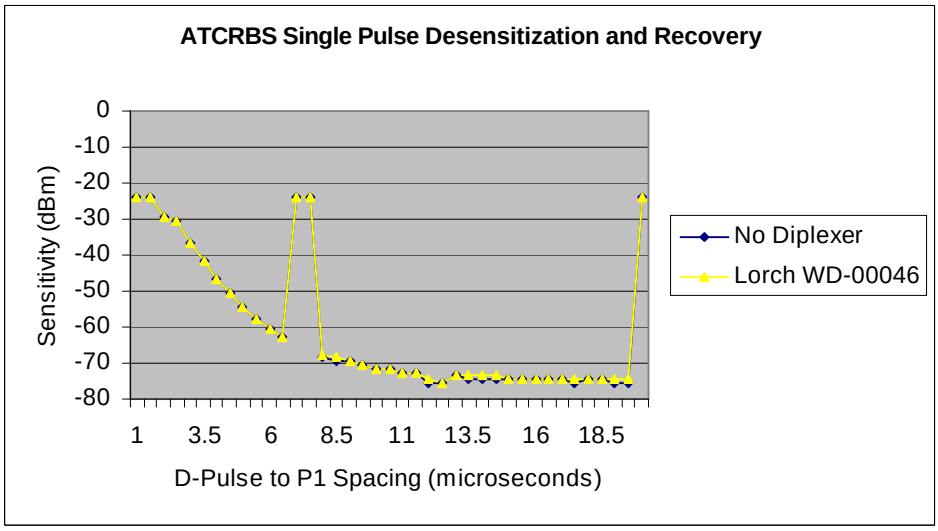

Figure 134 – ATCRBS Single Pulse Desensitization and Recovery, Transponder MS-1

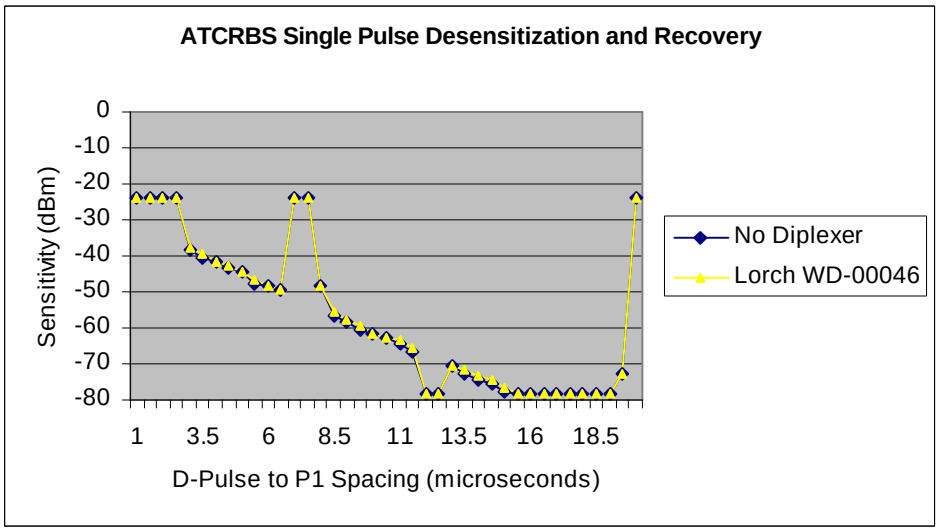

Figure 135 – ATCRBS Single Pulse Desensitization and Recovery, Transponder MS-2

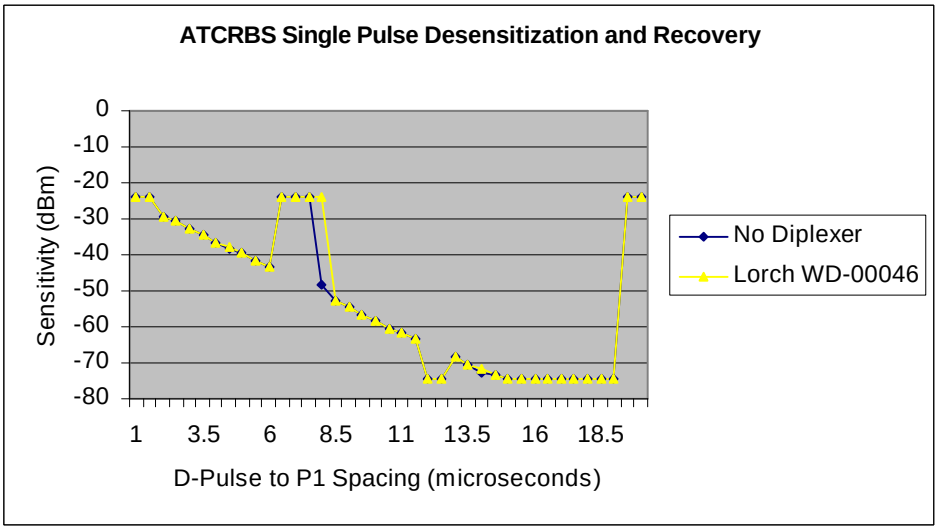

Figure 136 – ATCRBS Single Pulse Desensitization and Recovery, Transponder MS-3

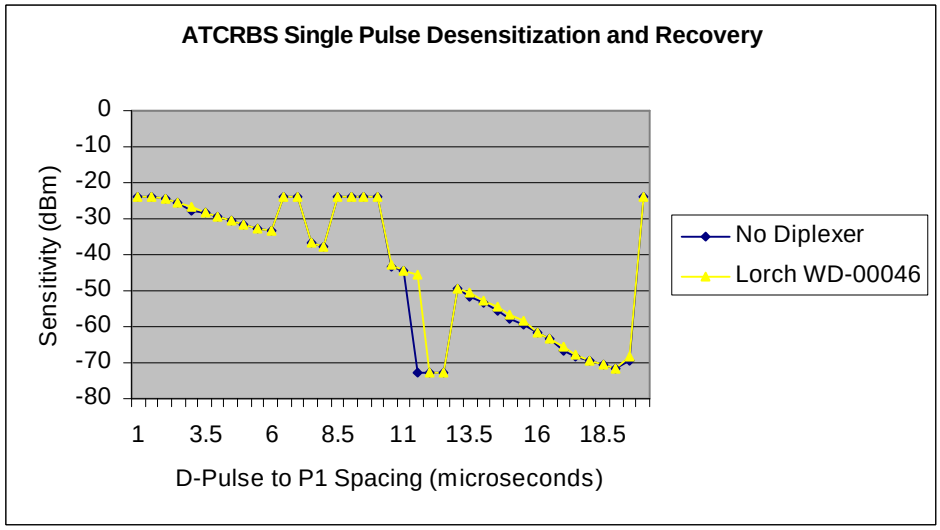

Figure 137 – ATCRBS Single Pulse Desensitization and Recovery, Transponder A-1

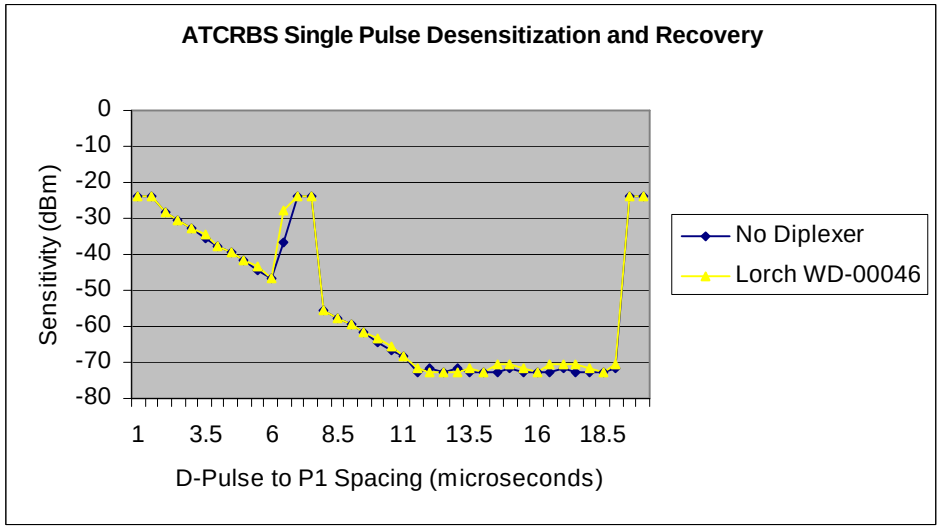

Figure 138 – ATCRBS Single Pulse Desensitization and Recovery, Transponder A-2

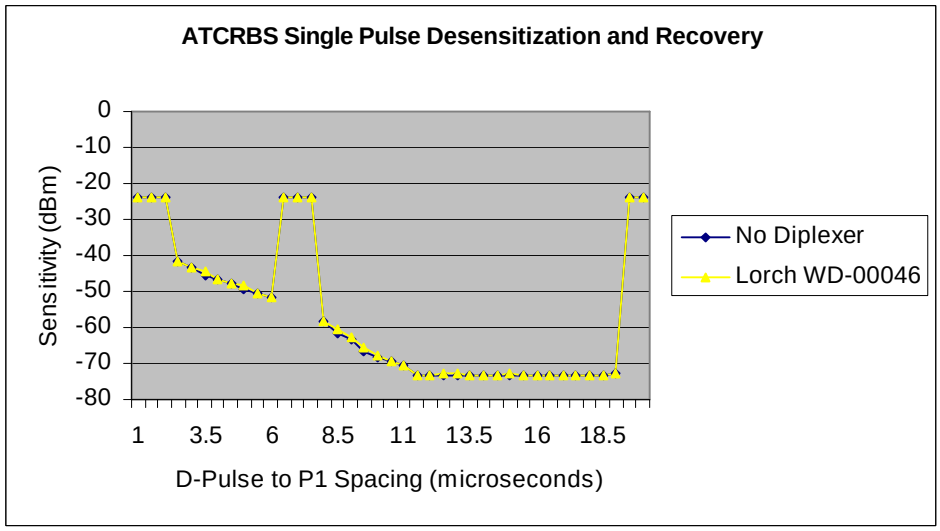

Figure 139 – ATCRBS Single Pulse Desensitization and Recovery, Transponder A-3

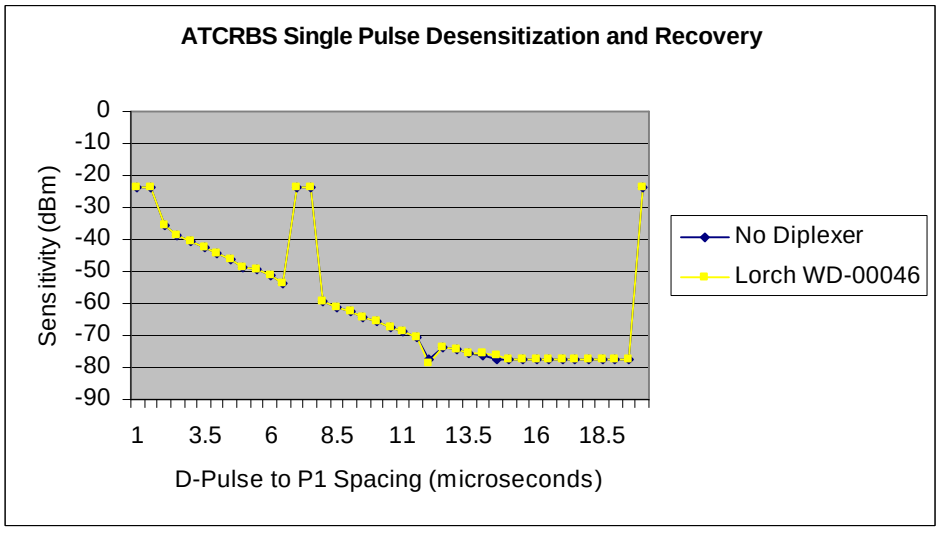

Figure 140 – ATCRBS Single Pulse Desensitization and Recovery, Transponder A-4

Conclusions

If a UAT ADS-B system is to be installed on an aircraft, sharing the existing ATC transponder antenna using a Diplexer that meets the specifications as defined in RTCA/DO-282A is considered a viable option. Four of the parameters tested were affected by the Diplexer/UAT installation, but in each case the effect was not enough to push the ATC transponder performance beyond acceptable limits. Table 4 summarizes the test results. In the table, parameters labeled "none" under measured effects are those that showed no measurable effect within the accuracy of the test system. The test system measurement accuracy either met or exceeded the specified test conditions in the MOPS.

TEST PARAMETER	**MEASURED EFFECT**
Reply Power	0.24 to 0.34 dB loss
Reply Frequency	None
Reply Delay (ATCRBS & Mode S)	Increased 0.01 to 0.012 microseconds
Reply Delay Jitter (ATCRBS & Mode S)	None
Reply Pulse Spacing (ATCRBS & Mode S)	None
Reply Pulse Shape (ATCRBS & Mode S)	None
Undesired Replies	UAT transmission triggered ATCRBS replies with 1 transponder (about 3 in 60 seconds)
Sensitivity (ATCRBS & Mode S)	0.24 to 0.26 dB loss
Dynamic Range	None
Sensitivity Variation with Frequency	None
Bandwidth	None
Pulse Position Tolerance (ATCRBS & ATCRBS/Mode S)	None
Pulse Duration Tolerance (ATCRBS & ATCRBS/Mode S)	None
Pulse Level Tolerance P4 (ATCRBS/Mode S)	None
Sync Phase Reversal Position Tolerance (Mode S)	None
SLS Decoding (ATCRBS & ATCRBS Mode S)	None
SLS Pulse Ratio (ATCRBS & ATCRBS/Mode S)	None
Suppression Duration	None
Suppression Reinitiation	None
Recovery From Suppression	None
Mode S SLS	None
ATCRBS Desensitization Pulse and Recovery	None

Table 4 – Diplexer Test Summary

The Reply Power and Receiver Sensitivity of the transponders were reduced a fraction of a dB through the Diplexer. This is expected due to the insertion loss of the transponder channel of the Diplexer that is specified to be 0.5 dB maximum. This should not be a detriment to proper operation as long as the net power and sensitivity at the antenna after installation are within specification.

The reply delay showed an increase of about 11 nanoseconds with the Diplexer. This is an effect of the sum of the 1030 MHz interrogation and the subsequent 1090 MHz reply each being delayed through the Diplexer. The connection in the aircraft of a transponder to the antenna results in a cable delay determined by the length and characteristics of the installed cabling. The installation with a Diplexer will include the combined Diplexer and cable delay. The delay through the Diplexer is an insignificant impact to the installation, given the tolerance allowed in delay in the transponder itself.

The Undesired reply rate was measured by monitoring ATCRBS and Mode S reply transmissions without interrogating the transponder. With the Diplexer and UAT installed and operating with the transponder, one of the transponders exhibited a low rate of unsolicited ATCRBS replies. This was caused by the low-level UAT signal leakage into the transponder channel of the Diplexer. There were no unsolicited Mode S replies with any of the transponders. The undesired reply rate for ATCRBS modes is required to be 5 replies per second or less averaged over a 30 second interval. (This is the requirement for Mode S transponders – RTCA/DO-181C) The MOPS for Airborne ATC Transponder Systems (DO-144) requires that the random triggering rate not exceed 30 replies per second. This latter requirement is after installation with all possible interfering equipment operating. Although the undesired reply rate caused by the UAT/Diplexer installation under these test conditions is well below spec, subsequent testing showed that either increasing the UAT transmit power slightly or reducing the channel isolation of the Diplexer slightly showed an increase in undesired replies. Unsolicited replies would even be possible without the use of a Diplexer depending on UAT transmit power and proximity of antennas. Therefore, the requirement that UAT equipment drive the mutual suppression bus to the transponder be used to inhibit the transponder receiver during UAT transmissions.

Although there was no test data that indicated that the Diplexer directly affects the transponder reply frequency (1090 MHz), the Diplexer installation does affect VSWR. Test results verified that ATCRBS transponders were more susceptible to VSWR variations than Mode S transponders. Proper tuning of the installed cabling will result in correcting such effects.